AN

ELEMENTARY MANUAL

ON

STEAM AND THE STEAM ENGINE.

STANDARD PRACTICAL TEXT-BOOKS.

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ELEMENTARY MANUAL

ON

STEAM AND THE STEAM ENGINE.

SPECIALLY ARRANGED FOR THE USE OF FIRST-YEAR SCIENCE AND ART, CITY AND GUILDS OF LONDON INSTITUTE AND OTHER ELEMENTARY ENGINEERING STUDENTS.

BY

ANDREW JAMIESON, M.Inst.C.E.

PROFESSOR OF ELECTRICAL ENGINEERING, THE GLASGOW AND WEST OF SCOTLAND TECHNICAL COLLEGE; MEMBER OF THE INSTITUTION OF ELECTRICAL ENGINEERS; FELLOW OF THE ROYAL SOCIETY, EDINBURGH;

AUTHOR OF

"TEXT-BOOK OF STEAM AND STEAM ENGINES," "ELECTRICAL RULES AND TABLES," "APPLIED MECHANICS," "MAGNETISM AND ELECTRICITY," ETC.

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1897.

PREFACE TO THE FIFTH EDITION.

THE Fifth Edition has been carefully revised, and brought up to date. The questions set at the 1895 and 1896 Examinations of the Science and Art Department in "Elementary Steam" have, as far as possible, been inserted at the end of the several Lectures to which they belong, whilst the remainder have been put into an Appendix at the end of the book with references to the sections in which the subjects are treated. I am indebted to Mr. Robert M. Anderson and Mr. David Robertson for assistance in connection with the revisal of this edition.

ANDREW JAMIESON.

THE GLASGOW AND WEST OF SCOTLAND
TECHNICAL COLLEGE,
September 1896.

INSTRUCTIONS TO BE FOLLOWED IN THE WRITING OF HOME EXERCISES.

1. Put the date of handing-in each exercise at the right hand top corner.

2. Leave a margin an inch wide on the left hand side of each page; and in the margin place the number of the question, and nothing more.

3. Leave a space of at *least* four lines between your answers for remarks or corrections.

4. Be sure you understand *exactly* what the question requires you to answer, then give *all* it requires, but *no more*. If unable to answer any question, write down its number and the reason why.

5. Make your answers concise, clear, and exact; and accompany them, whenever practicable, by an illustrative sketch.

6. Make all sketches large, open, and in the centre of page, and do not crowd writing about them.

(NOTE.—The character of sketches will be considered in awarding marks.)

7. Every sketch must be accompanied by an "Index of parts" written immediately beneath it, and must accompany the answer it is designed to illustrate.

(NOTE.—The initial letter or letters of the name of the part must be used, and not A, B, C, or 1, 2, 3, &c.)

8. Unless specially asked by the question, every sketch must be accompanied by a concise written description.

9. Every answer which receives less than five marks must be re-written correctly for next evening, before the usual class work, and headed "Re-written."

REMARKS.—Students are strongly recommended to write out each answer in scroll first, and then to compare it with the question. After committing the answer to their book, they should then read it over a second time, to correct any errors they may discover. Reasonable and easily intelligible contractions are permitted. Students are invited to ask questions and explanations regarding anything they do not understand. Except in special cases, arrears of Home work *will not receive marks.*

N.B.—Students who from any cause have been absent from a lecture should send a post card or note of explanation to their teacher. If they miss any exercise or exercises they must state the reason (in red ink or underlined), in their exercise books when handing them in next night.

PREFACE.

THIS Manual has been written expressly for Apprentice Engineers and Elementary or First-year Students studying Steam and the Steam Engine. It covers the elementary stage of the Science and Art Department's Examination in Steam, and, for the most part, the First Steam Engine Section of the City and Guilds of London Institute's Technological Examination in Mechanical Engineering.

The book contains twenty-eight short Lectures, with a selection of Questions at the end of each Lecture, systematically arranged in the order of treatment of the subject. The first three Lectures are devoted to the mensuration of lengths, surface areas, and volumes. It is most desirable that the student should know how to find the circumference, area, and volume of a cylinder, &c. &c., before he commences to study steam and the steam engine. If arithmetic were properly taught in schools, there would be no necessity for introducing mensuration here; but unfortunately, with the Educational Codes at present in force, arithmetic is not mastered nearly so thoroughly as it used to be—at least in Scotland! Lectures IV. to XVII. are devoted to the consideration of elementary phenomena in connection with heat and steam, and their actions on the cylinder and the condenser of an engine. This may be termed the preparatory or theoretical portion of the book. Lectures XVIII. and XIX. explain the difference between Newcomen's and Watt's, between single- and double-acting, and between simple expansion, compound, triple, and quadruple expansion engines. Here a little history is introduced, but throughout the book historical events and descriptions of defunct forms of steam engines are avoided as far as possible, for the junior student should first master the principles and action of the steam engine

of the present day before attempting to appreciate the many successful and unsuccessful attempts of early inventors. The remainder of the book is chiefly descriptive, and, since the space at my disposal was necessarily limited, I have confined my remarks and diagrams, for the most part, to an explanation of the general construction and details of one good modern compound marine engine and boiler.

The book, as a whole, forms an easy introduction to my larger and more advanced *Text Book on Steam and Steam Engines*, issued by the same publishers. It may be thoroughly discussed in the minimum number of lectures demanded by the Science and Art Department, if the student systematically works out at home a few of the Questions given at the end of each Lecture, and hands them to his teacher for correction. This system of combining short lectures with numerous examples and sketches to be worked out by the student at home, produces the most satisfactory results.

I have been much indebted to Reed's excellent *Engineer's Handbook* to the Local Marine Board Examinations for Certificates of Competency as First and Second-class Engineers, and to Mr. Somerscales' Collection of Questions on the Steam Engine, for hints as to the treatment of the first three Lectures and some of the examples throughout the book. I have also to express my obligations to Mr. Middleton, Teacher, Orkney, who kindly examined the manuscript of the part on Mensuration; and also to Mr. Wm. C. Borrowman, Wh.Sch., who has assisted me in revising most of the proofs.

If any errors should be observed by readers, or answers obtained to unanswered arithmetical questions, I shall feel much obliged for an early note of them, and I shall also gratefully acknowledge the receipt of any suggestions or communications tending to increase the usefulness of the work, as my desire is, as far as possible, to keep it abreast of the times.

ANDREW JAMIESON.

THE GLASGOW AND WEST OF SCOTLAND
TECHNICAL COLLEGE,
September 1888.

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ELEMENTARY MANUAL

ON

STEAM AND THE STEAM ENGINE.

LECTURE I.

CONTENTS.—Importance of mastering Elementary Mensuration—Tables of Lineal and Square Measure—To Find the Area of a Square; an Oblong; any Parallelogram; a Triangle; a Trapezoid; a Trapezium; with Examples.

As mentioned in the Preface, we consider it of more importance that the student, when commencing the study of "Steam and the Steam Engine," should be well drilled in Mensuration than in the historical parts of the subject. However interesting and instructive the history of the Rise and Progress of the Steam Engine may be, experience has proved to the author that junior students cannot form a proper appreciation of the gradual growth and improvements that have, from time to time, been made in the forms and actions of steam engines until they have first thoroughly mastered the fundamental principles of measurement, the properties of heat, of steam, and the action of the steam engine as made and worked at present. In following this view, we have consequently omitted almost all reference to historical events or antique forms of apparatus;* but have, instead, devoted the first three lectures to the common rules used by engineers in estimating lengths, areas, volumes, and weights of different forms of apparatus and pieces of machinery, or what is generally termed "taking out quantities." The student *must*

* For a short history of the Rise and Progress of the Steam Engine in its various forms, students may refer to the author's more advanced Treatise on Steam and Steam Engines, issued by the same publishers.

thoroughly master these simple rules and their applications, because they are of every-day use in the workshop and the drawing-office.

We shall assume that the student is familiar with the elements of arithmetic, and of algebra, up to and including simple equations, with the first or elementary stages of freehand drawing, of practical plane and solid geometry, and of machine-construction drawing as laid down in the Syllabus of the Science and Art Department.

Tables of Lineal and Square Measure.

Length.

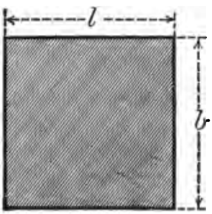
12	inches	make	1 foot
3	feet	,,	1 yard
6	,,	,,	1 fathom
5280	,,	,,	1 mile
6080	,,	,,	1 knot

Surface.

144	square inches	make	1 square foot
9	,, feet	,,	1 ,, yard

·007 × square inches = square feet

1. To Find the Area of a Square.



DEFINITION.—*A square is a plane four-sided figure, having all its sides equal, and all its angles right angles.* Or, a square is a rectangle with all its sides equal.

RULE.—*Multiply the length, l, by the breadth, b.* Or, square one of the sides.

EXAMPLE I.—One side of a square piece of metal is 2·5 feet. What is its area in square feet and in square inches? Applying the above rule we have—

$$2{\cdot}5 \times 2{\cdot}5 \text{ (or } 2{\cdot}5^2) = 6{\cdot}25 \text{ square feet.}$$

Now, since there are 144 square inches in 1 square foot, how many square inches will there be in 6·25 square feet?

Let x stand for the number of square inches required, and put it into the 4th term. Put the known number of square inches, viz., 144, into the 3rd term. Now ask the question, Will the answer be greater or less?—Greater. Then put the greater of the other known quantities into the 2nd term, and the lesser into the 1st term. Thus:—

1st Term	:	*2nd Term*	::	*3rd Term*	:	*4th Term.*
1 sq. ft.	:	6·25 sq. ft.	::	144 sq. in.	:	x sq. in.

$$\therefore x = \frac{6{\cdot}25 \times 144}{1} = 900 \text{ square inches}$$

EXAMPLE II.—A square piece of boiler-plate is 30·25 square feet. What is the length of one of its sides in feet and in inches?

Here we have simply to reverse the process of finding the area—viz., to extract the square root of 30·25.

The $\sqrt{30{\cdot}25}$ is found thus:—

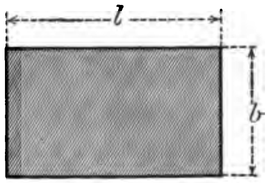
```
     5 ) 30·25 ( 5·5 feet length of side.
   + 5   25
   105)  525
         525
```

Or, 5·5 feet × 12 = 66 inches length of side.

2. To Find the Area of an Oblong or Rectangular Parallelogram or Rectangle.

DEFINITION.—*An oblong is a plane four-sided figure, whose opposite sides are equal, and whose angles are all right angles.*

RULE.—*Multiply the length, l, by the breadth, b.*



EXAMPLE III.—A boiler-plate is 10 feet long by 4 feet 6 inches broad. What is its area in square feet, and what is its weight at 30 lbs. per square foot?

$$\text{Area} = l \times b = 10 \text{ feet} \times 4{\cdot}5 \text{ feet} = 45 \text{ square feet.}$$

$$\text{And } 1 : 45 :: 30 \text{ lbs.} : x \text{ lbs.}$$

$$\therefore x = \frac{45 \times 30}{1} = 1350 \text{ lbs.}$$

EXAMPLE IV.—A boiler-plate weighs 40 lbs. per square foot, and its total weight is 1800 lbs. Its breadth is 4 feet 6 inches. What is its length?

First find the number of square feet in the plate.

$$\text{Thus, } 40 \text{ lbs.} : 1800 \text{ lbs.} :: 1 \text{ square foot} : x \text{ square feet.}$$

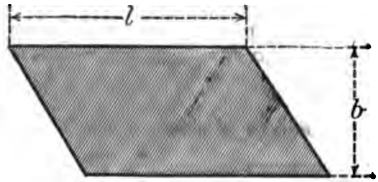
$$\therefore x = \frac{1800 \times 1}{40} = 45 \text{ square feet.}$$

Second, divide this 45 square feet by the breadth, 4·5 feet,

$$\therefore 45 \div 4{\cdot}5 = 10 \text{ feet long.}$$

3. To Find the Area of any Parallelogram.

DEFINITION.—*A parallelogram is a plane four-sided figure, whose opposite sides are parallel and equal.*



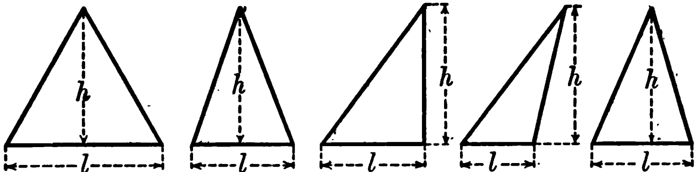
RULE. — *Multiply the length, l, by the perpendicular height or breadth, b.*

EXAMPLE V.—The length of a plate is 7 feet, its perpendicular breadth is 5 feet. What is its area in square feet?

$$\text{Area} = l \times b = 7 \times 5 = 35 \text{ sq. ft.}$$

4. To Find the Area of a Triangle.

DEFINITION.—*A triangle is a plane figure bounded by three sides.* The following figures show different forms of triangles:—



Equilateral *Isosceles* *Right Angled* *Obtuse* *Acute Angled*

RULE.—*Since a triangle is half of a parallelogram of same length and height, multiply base or length, l, by half the height, h.*

EXAMPLE VI.—The base or length of a triangle is 2 feet 6 inches long, while the height is 3 feet 6 inches. Find its area in square feet and in square inches.

$$\text{Area} = l \times \frac{h}{2} = 2{\cdot}5 \text{ feet} \times \frac{3{\cdot}5}{2} \text{ feet} = 2{\cdot}5 \times 1{\cdot}75 = 4{\cdot}375 \text{ square feet;}$$

$$\therefore\ 4{\cdot}375 \text{ square feet} \times 144 = 630 \text{ square inches.}$$

EXAMPLE VII.—The area of a triangle is 3·375 square feet, its base or length is 2 feet 3 inches: what is its height?

$$\text{Area} = l \times \frac{h}{2};$$

$$3{\cdot}375 \text{ square feet} = 2{\cdot}25 \text{ feet} \times \frac{h}{2}$$

$$\therefore\ \frac{3{\cdot}375 \times 2}{2{\cdot}25} = h = 3 \text{ feet.}$$

Or, by proportion:—If we have a triangle 1 square foot in area, whose base or length is 1 foot long, then its height must be 2 feet. Consequently, what must be the height, h, of a tri-

angle whose area is 3·375 square feet, and base or length is 2 feet 3 inches?

2·25 ft. base : 1 ft. base :: 2 ft. height : h
1 sq. ft. area : 3·375 sq. ft. area.

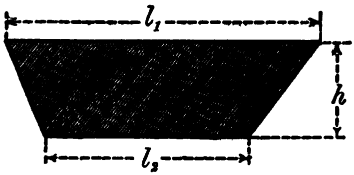
Since the product of the extremes is equal to that of the means, we have,

$$h \times 2{\cdot}25 \times 1 = 2 \times 1 \times 3{\cdot}375;$$

$$\text{Or,} \quad h = \frac{2 \times 3{\cdot}375}{2{\cdot}25} = 3 \text{ feet (as before).}$$

5. To Find the Area of a Trapezoid.

DEFINITION.—*A trapezoid is a plane four-sided figure having two of its sides parallel.*



RULE.—*Multiply half the sum of the two parallel sides (l_1 and l_2) by the perpendicular breadth, or height, h, between them.*

$$\text{Or, area} = \frac{l_1 + l_2}{2} \times h.$$

EXAMPLE VIII.—Find the area of a four-sided plate, with two parallel sides, $l_1 = 6$ feet, $l_2 = 3$ feet 6 inches, and breadth = 3 feet.

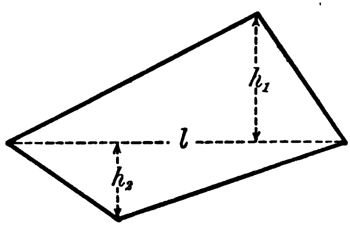
$$\text{Area} = \frac{l_1 + l_2}{2} \times h = \frac{6 + 3{\cdot}5}{2} \times 3 = 14{\cdot}25 \text{ square feet.}$$

6. To Find the Area of a Trapezium or any Quadrilateral.

DEFINITION.—*A trapezium is a plane figure bounded by four unequal straight lines. It is, therefore, different from a square, an oblong, and a parallelogram.*

RULE.—1st. Join any two of the opposite angles by a dotted line, thus dividing the figure into two triangles. *Measure this line, and call it the base or length, l, of each triangle.*

2nd. *Measure from the base line, l, the perpendicular heights, h_1 and h_2, of each triangle.*



3rd. *Find the area of each triangle by the rule already given; their sum is the area of the whole figure.*

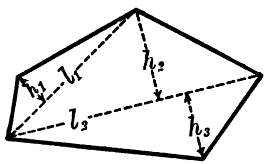
$$\text{Or, area} = l \times \frac{h_1}{2} + l \times \frac{h_2}{2} = l\left(\frac{h_1 + h_2}{2}\right).$$

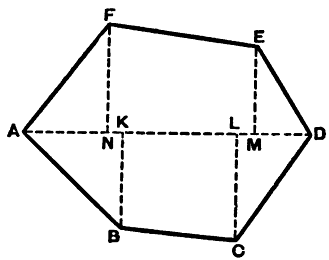
EXAMPLE IX.—In an irregular four-sided plate of trapezium form, the distance, $l = 5$ feet, $h_1 = 2$ feet, and $h_2 = 1$ foot 6 inches. Find the superficial area of the plate.

$$\text{Area} = l\left(\frac{h_1 + h_2}{2}\right) = 5\left(\frac{2 + 1\cdot5}{2}\right) = 8\cdot75 \text{ square feet.}$$

7. To Find the Area of any Rectilineal Figure or Polygon.

DEFINITION.—*A rectilineal figure is a plane figure bounded by straight lines.* The sides may be of any number, according to the shape of the figure.





RULE.—*Divide the figure into convenient parts. Find the area of each part, and the sum of the parts will be the area of the whole figure.*

Note.—In general, the parts into which the rectilineal figure can be most conveniently divided will be triangles; but in certain cases a square, a parallelogram, or a trapezoid may form one or more of the parts.

EXAMPLE X.—Referring to the first figure above, let it be divided as shown by the dotted lines, and let $l_1 = 5$ feet, $l_2 = 6$ feet, $h_1 = 1$ foot, $h_2 = 3$ feet, and $h_3 = 2$ feet. Find the area of the figure.

$$\text{Area} = l_1 \times \frac{h_1}{2} + l_2 \times \frac{h_2}{2} + l_2 \times \frac{h_3}{2} = l_1 \times \frac{h_1}{2} + l_2\left(\frac{h_2 + h_3}{2}\right)$$

$$= 5 \times \frac{1}{2} + 6\left(\frac{3 + 2}{2}\right)$$

$$= 2\cdot5 + 6 \times 2\cdot5$$

$$= 17\cdot5 \text{ square feet.}$$

EXAMPLE XI.—Referring to the last figure, take the dimensions and working out given in Todhunter's *Mensuration for Beginners*, where ABCDEF is a six-sided figure: BK, CL, EM, and FN are perpendiculars on AD. The following lengths are in feet:—

$$BK = 3,\ CL = 4,\ EM = 4{\cdot}7,\ FN = 5{\cdot}1.$$

Also $AK = 3{\cdot}4$, $KL = 3{\cdot}2$, $LD = 4{\cdot}1$, $AN = 3{\cdot}3$, $NM = 5{\cdot}3$.

It follows from these lengths that $AD = 10{\cdot}7$, and that $AM = 8{\cdot}6$; hence $MD = 10{\cdot}7 - 8{\cdot}6 = 2{\cdot}1$.

The area of the triangle AKB	$= \frac{1}{2} \times 3{\cdot}4 \times 3$	$=$	$5{\cdot}1$	sq. ft.
The area of the trapezoid BKLC	$= \frac{1}{2} \times 7 \times 3{\cdot}2$	$=$	$11{\cdot}2$	„
The area of the triangle DLC	$= \frac{1}{2} \times 4{\cdot}1 \times 4$	$=$	$8{\cdot}2$	„
The area of the triangle ANF	$= \frac{1}{2} \times 3{\cdot}3 \times 5{\cdot}1$	$=$	$8{\cdot}415$	„
The area of the trapezoid FNME	$= \frac{1}{2} \times 9{\cdot}8 \times 5{\cdot}3$	$=$	$25{\cdot}97$	„
The area of the triangle EMD	$= \frac{1}{2} \times 2{\cdot}1 \times 4{\cdot}7$	$=$	$4{\cdot}935$	„
∴ The area of whole figure	= the sum	$=$	$63{\cdot}82$	„

Lecture I.—Questions.

1. If 7 bolts are pitched at 5 inches apart in a straight line, what is the distance between the centres of the outside bolts? *Ans.* 2 feet 6 inches.

2. There are 9 bolts in a straight line; the distance between the centres of the outside bolts is 3 feet 6 inches. What must be the pitch? *Ans.* 5·25 inches.

3. The distance between the centres of the outside bolts is 5 feet 10⅛ inches, the pitch is 6⅜ inches. How many bolts must there be in a straight line? *Ans.* 12 bolts.

4. A sheet of lead is 10′ 4″ square. Find its weight at 7 lbs. per square foot. *Ans.* 747·44 lbs.

5. What is the number of square inches in a rectangle which measures 24 inches long by 18 inches broad? *Ans.* 432.

6. Find the area of a rectangle which is 3 feet wide and 15 feet 4 inches long? *Ans.* 46 square feet.

7. A fire-grate is 5′ 6″ long and 3′ 1″ wide. How many square feet are there in it? *Ans.* 16·958.

8. A boiler plate is 13′ 6″ long and 2′ 11″ wide. What will it weigh at 35 lbs. per square foot? *Ans.* 1378·125 lbs.

9. A rectangular tank is 10′ long, 7′ wide, and 7′ high. What would be the cost of cementing the two sides and the top at 7*s.* 6*d.* per square yard? *Ans.* £8 15*s.*

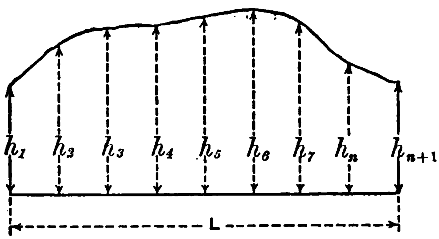
10. The base of a triangular plate is 2′ 6″ and the height is also 2′ 6″. What is the area in square feet and in square inches? *Ans.* 3·125 square feet, 450 square inches.

11. Find the area of a trapezoid, the parallel sides being 5 and 4 feet respectively, and the perpendicular distance between them being 2 feet. *Ans.* 9 square feet.

LECTURE II.

CONTENTS.—To Find the Area of a Four-sided Figure, one of whose Sides is a Curve—Simpson's Rule—To Find the Circumference of a Circle—The Superficial Area of a Cylinder—The Area of a Circle—The Circumference of an Ellipse—The Superficial Area of an Elliptical Cylinder—The Area of an Ellipse; with Examples.

1. To Find the Area of a Four-sided Figure, one of whose Sides is a Curve.



FIRST RULE.—*Divide the length, l, of the figure into, n, equal parts by lines* $h_1, h_2, \ldots h_{n+1}$ *drawn at right angles to the base line; add together the first and the last* $(h_1 + h_{n+1})$; *call this sum, A; add together all the intermediate ones* $(h_2 + h_3 + h_4$, *&c.*), *and call this sum, B.*

Then :— $$\left(\frac{A + 2B}{2}\right)\frac{L}{n} = \text{area of the figure.}$$

Where $\frac{L}{n}$ is the interval, or pitch, or length of each of the parts into which the figure is divided; for example, let the length $L = 20$ inches, and the number of equal parts, $n, = 10$.

Then the length of each part $= \frac{L}{n} = \frac{20}{10} = 2$ inches.

This rule is simply an approximate method, based upon the fact that the whole figure is divided into a number of little trapezoids. The curved part of each trapezoid, being short, is assumed to be a straight line; then the sum of the areas of the several trapezoids will be equal to the area of the whole figure.

$$\text{Area of 1st trapezoid} = \frac{1}{2}(h_1 + h_2) \times \frac{L}{n}$$

$$\text{Area of 2nd trapezoid} = \frac{1}{2}(h_2 + h_3) \times \frac{L}{n}$$

&c. &c.

$$\text{Area of last trapezoid} = \frac{1}{2}(h_n + h_{n+1}) \times \frac{L}{n}$$

$$\therefore \text{Area of whole figure} = \frac{1}{2}(h_1 + 2h_2 + 2h_3 + \ldots h_{n+1}) \times \frac{L}{n} \text{(the sum}$$

$$\left.\begin{array}{r}\text{of all the small}\\ \text{trapezoids)}\end{array}\right\} = \left[\frac{1}{2}(h_1 + h_{n+1}) + \frac{1}{2}(2h_2 + 2h_3 \ldots 2h_n)\right]\frac{L}{n}$$

$$= \left(\frac{A}{2} + \frac{2B}{2}\right)\frac{L}{n} = \left(\frac{A + 2B}{2}\right)\frac{L}{n} \text{ as above.}$$

Of course, the greater the number of equal parts into which the length of the figure is divided, the nearer will the answer be to the true area of the figure.

EXAMPLE I.—See the four-sided figure (p. 119) of Watt's "diagram of work," which is divided into ten equal parts.

Let the whole length of the figure, L, be 100 inches; then $\frac{L}{n} = 10$ inches as the interval between each division, and let the numbers representing the perpendiculars, or ordinates, be also reckoned in inches.

Let A = the sum of the 1st and last perpendiculars or ordinates,
$= 100 + 25 = 125.$

Let B = the sum of the intermediate ordinates,

$$= 100 + 100 + 83{\cdot}\dot{3} + 62{\cdot}5 + 50 + 41{\cdot}\dot{6} + 35{\cdot}7 + 31{\cdot}25 + 27{\cdot}\dot{7} = 533{\cdot}23.$$

$$\therefore 2B = 533{\cdot}23 \times 2 = 1066{\cdot}46.$$

Then the whole area :—

$$= \left(\frac{A + 2B}{2}\right)\frac{L}{n}$$

$$= \left(\frac{125 + 1066{\cdot}46}{2}\right)\frac{100}{10}$$

$$= 5957{\cdot}3 \text{ square inches.}$$

Note.—The mean length of all the ordinates is evidently—

$$\left(\frac{A + 2B}{2}\right)\frac{1}{n} = \frac{5957{\cdot}3}{100} = 59{\cdot}573 \text{ inches,}$$

which is very near the arithmetical mean worked out at p. 119.

SECOND RULE, called SIMPSON'S RULE.—*Divide the length of the figure into an even number, n, of equal parts, and draw ordinates through the points of division* (AS BEFORE) *to touch the boundary lines. Add together the first and the last ordinates; call the sum,* A; *add together the even ordinates,* 2nd, 4th, 6th, &c., *and call the sum,* B; *add together the odd ordinates,* 3rd, 5th, 7th, &c. (except the first and last), *and call the sum,* C, and let L be length of the figure as before, viz., 100 inches.

Then:—

$$\left(\frac{A + 4B + 2C}{3}\right) \times \frac{L}{n} = \text{area of the figure.}$$

This rule is based on the assumption that the curved part of the figure is either a straight line or a parabola, and, of course, it is only approximate for figures bounded by curves differing from these forms.*

EXAMPLE II.—Apply Simpson's rule to the same figure as in Example I.

$$\text{Then, } A = 100 + 25 = 125, \text{ as before,}$$
$$\text{and } B = 100 + 83\cdot\dot{3} + 50 + 35\cdot71 + 27\cdot\dot{7} = 296\cdot83.$$
$$\therefore 4B = 296\cdot83 \times 4 = 1187\cdot32,$$
$$\text{and } C = 100 + 62\cdot5 + 41\cdot\dot{6} + 31\cdot25 = 235\cdot42.$$
$$\therefore 2C = 235\cdot42 \times 2 = 470\cdot84.$$

Then the whole area:—

$$= \left(\frac{A + 4B + 2C}{3}\right)\frac{L}{n}$$
$$= \left(\frac{125 + 1187\cdot32 + 470\cdot84}{3}\right)\frac{100}{10}$$
$$= \frac{1783\cdot16}{3} \times 10 = 5944 \text{ square inches.}$$

And the mean length of all the ordinates is evidently

$$\frac{5944}{100} = 59\cdot44 \text{ inches,}$$

which is a little less than by the former rule. This latter rule of Simpson's is, however, more correct than the former or easier rule; but if a sufficient number of ordinates be taken with the first rule, it produces a result near enough for most practical purposes.

This problem of finding the area of a figure bounded on one side by a curve is of great importance to engineers. It is used, as we shall see afterwards, for finding the area of the indicator figure representing the work done in one stroke of an engine, as well as the

* See Todhunter's *Mensuration for Beginners*, p. 110, for an elementary explanation of this rule.

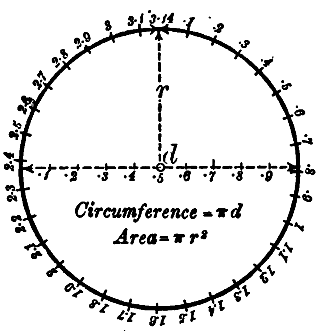
diagrams of work done by machines generally. It is also used for finding the area of the immersed midship or other section of ships.

A "rough and ready" way of finding the area of any very irregular figure is, to plot the figure to scale on squared paper where the side of each square is $\frac{1}{10}$ or ·1 of a square inch, and to count the number of squares within the area of the figure; then multiply by the scale to which the figure is drawn.

Another and very accurate method is to run round the figure with an integrating machine, such as Amsler's or Boys' Integrator, which sums up automatically the area of the whole figure, however irregular, to any particular scale.

2. To Find the Circumference of a Circle from its Diameter or its Radius.*

DEFINITIONS.—A CIRCLE *is a plane figure bounded by one line, which is called the circumference; and is such, that all straight lines drawn from a certain point within the figure to the circumference are equal to one another. This point is called the centre of the circle.*



A DIAMETER *of a circle is a straight line drawn through the centre, and terminated both ways by the circumference.*

A RADIUS *of a circle is a straight line drawn from the centre to the circumference.* A radius is therefore half of a diameter.

RULES.—1. *Multiply the diameter by 22, and divide the product by 7.*

Or, 2. *Multiply the diameter by $3\frac{1}{7}$ or by 3·1416.*

Note.—The Greek letter, π, is universally used to denote the ratio of the circumference of a circle to its diameter, (*i.e.*, $\pi = 3·1416$ or $\frac{22}{7}$,) while the letter, d, is often used to denote the diameter, and, r, the radius.

$$\therefore \text{The circumference of a circle} = \pi d = 2\pi r.$$

The last expression is the more easily remembered.

Note.—To thoroughly understand the most exact method of finding the ratio of the circumference of a circle to its diameter requires a knowledge of higher mathematics, but the approximate method graphically

* For definitions and the mensuration of arcs, chords, segments, sectors, and zones of circles, see Todhunter's *Mensuration for Beginners*.

represented by the figure is very easily understood, viz.: *Divide the diameter into* 10 *equal parts, and, with one of these parts, divide off the circumference, and it will be found that there are* 31·4 *of them, or* 3·14 *times the diameter.*

EXAMPLE III.—(*a*) What is the circumference of a circle whose diameter is 10 inches?

Circumference $= \pi \times d = 3{\cdot}1416 \times 10'' = 31{\cdot}416$ inches.

(*b*) What is the circumference of a circle whose radius is 10 inches?

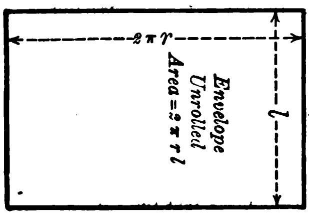
Circumference $= 2\pi r = 2 \times 3{\cdot}1416 \times 10'' = 62{\cdot}832$ inches.

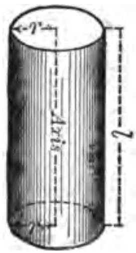
(*c*) What is the diameter, and what is the radius, of a circle whose circumference is 9·4248 feet?

$$\text{Circumference} = \pi \times d.$$
$$\therefore\ 9{\cdot}4248 \text{ feet} = 3{\cdot}1416 \times d.$$
$$\frac{9{\cdot}4248}{3{\cdot}1416} = d = 3 \text{ feet diameter.}$$
$$\text{But } \frac{d}{2} = r = \frac{3 \text{ feet}}{2} = 1{\cdot}5 \text{ foot radius.}$$

3. To Find the Superficial Area or the Envelope of a Solid or of a Hollow Right Cylinder.

DEFINITION.—*A* CYLINDER *is either a solid or hollow figure, produced by turning a rectangle (of length, l, and breadth, r) round one of its sides (termed the axis), which remains fixed.*





RULE.—Since the surface of a cylinder is precisely the same as the area of an oblong or rectangular parallelogram, whose length, l, is the same as the length, l, of the cylinder, and breadth, b, corresponds to the circumference, $2\pi r$, of the cylinder, *the rule* for finding the superficial area of the envelope naturally is:—

Multiply the circumference of the cylinder by its length (both sizes being, of course, in the same unit).

Or, area $= \pi d \times l = 2\pi r \times l$.

EXAMPLE IV.—The diameter of a steam engine cylinder is 30 inches, and the total internal length (including depth of piston and clearance length) is 3 feet. What is the superficial area of the interior of the cylinder in square feet and in square inches?

$$\text{Area} = \pi d \times l$$
$$\text{,,} = 3{\cdot}1416 \times 2{\cdot}5 \text{ feet} \times 3 \text{ feet}$$
$$\text{,,} = 23{\cdot}562 \text{ square feet}$$
$$\therefore \text{,,} = 23{\cdot}562 \times 144 \text{ square inches}$$
$$\text{,,} = 3392{\cdot}93 \text{ square inches.}$$

EXAMPLE V.—In each of the boilers of the s.s. *St. Rognvald* (see Lecture XXVI.), there are 324 tubes (249 ordinary tubes and 75 stay tubes), each tube being $3\frac{1}{4}$ inches outside diameter, and 7 feet long. What is their total heating-surface in contact with the water in the boiler in square feet?

First find the superficial area of *one* tube.

$$\text{Area} = \pi d \times l$$
$$= 3{\cdot}1416 \times 3{\cdot}25 \text{ (inches)} \times 7 \text{ (feet)} \times 12 \div 144$$
$$= 5{\cdot}96 \text{ square feet.}$$

Note.—The student should always endeavour to adopt that method by which he will arrive at a correct answer in the shortest time. Consequently, if, instead of working out a whole string of figures as indicated above, he first finds the diameter of the tube in decimals of a foot, and then cancels the 7's, he will find the operation both quicker and less irksome. Thus:—

$$d = 3\tfrac{1}{4} \text{ inches} = 3{\cdot}25 \text{ inches} = \frac{3{\cdot}25}{12} = {\cdot}271 \text{ foot,}$$

and $\pi = \frac{22}{7}$.

$$\therefore \text{Area} = \frac{22}{7} \times {\cdot}271 \times 7 \text{ (feet)}$$
$$= 22 \times {\cdot}271$$
$$= 11 \times 2 \times {\cdot}271$$
$$= 11 \times {\cdot}542$$
$$= 5{\cdot}962 \text{ square feet (as before).}$$

∴ The surface area of the whole 324 tubes

$$= 324 \times 5{\cdot}96$$
$$= 1931 \text{ square feet.}$$

4. To Find the Area of a Circle.

RULES.—*Multiply* ·7854 *by the square of the diameter.*

Or, *multiply* 3·1416 *or* $\frac{22}{7}$ *by the square of the radius.*

Thus the area of a circle = $\cdot 7854 d^2 = \frac{\pi}{4} d^2$.*

$$\text{Or,} = 3\cdot 1416 r^2 = \frac{22}{7} r^2 = \pi r^2.$$

The last of these expressions, viz., πr^2, is the easiest to remember, and is the one which we shall most frequently adopt.

EXAMPLE VI.—The diameter of a steam engine cylinder is 1 foot 2 inches. Find its area in square inches.

$$\text{Area} = \pi r^2 = \frac{22}{\cancel{7}} \times \cancel{7} \times 7$$
$$= 22 \times 7$$
$$= 154 \text{ square inches.}$$

Note.—This example is specially chosen to show that it is quicker and easier to adopt $\frac{22}{7}$, and to cancel the 7's, than to take $\pi = 3\cdot 1416$.

The area of the cylinders of engines is always reckoned in square inches, because the pressure of the steam or gas admitted into them is recorded or indicated in lbs. per square inch.

* For those who prefer the expression ($\cdot 7854 d^2$ = area of a circle), we here draw attention to a very easy method of multiplying by $\cdot 7854$, as given in Reed's *Engineer's Hand-Book.*

The diameter of a circle is 3·5 inches. Find the area.

```
 3·5 × 3·5        12·25 × ·7854
 3·5                  7
 ----             -----
 175              8575
105                 8575   = 1st line of multiplication repeated
-----               17150  = 1st   ,,          ,,         × 2
12·25                17150 = 3rd   ,,  repeated
                 ---------
                 9·621150  = area in square inches.
```

"The method of procedure is as follows:—The number expressing the square of the diameter is multiplied first by 7 by common multiplication. This line is put down a second time, but removed one place to the right instead of to the left as in ordinary multiplication. *This line* is now multiplied by 2, and its result put down one place to the right, and again put down one place to the right. The sum of these products is the same as if we had multiplied by ·7854 in the ordinary manner."

```
7
 7
 14
  14
-----
·7854
```

"The process may be rendered clearer, if the reason for the method be explained. If we put down the number 7, then one place to the right put it down again; then multiply it by 2, and put product one place more to the right, then put this down again one place to the right, and add them all up, we clearly get the number 7854; therefore if we multiply in this order we get the same result as if ·7854 had been used in full."

EXAMPLE VII.—The cross area of a cylinder is 1963·5 square inches. What is its diameter in feet and inches?

$$\text{Area} = \pi r^2.$$
$$1963{\cdot}5 = 3{\cdot}1416 \times r^2.$$
$$\therefore \frac{1963{\cdot}5}{3{\cdot}1416} = r^2 = \underline{625}.$$
$$\therefore \sqrt{625} = r = 25'' \therefore d = 50 \text{ inches}$$
$$\text{or } d = 4 \text{ feet } 2 \text{ inches.}$$

Or, by using the fraction $(\frac{22}{7})$, and dividing the 22 and the 1963·5 by 2, and then dividing numerator and denominator by 11, and multiplying by the 7, we get r^2.

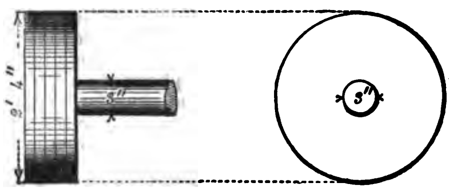
Thus:— $$1963{\cdot}5 = \frac{22}{7} r^2.$$

$$\frac{\overset{\overset{89{\cdot}25}{\cancel{981{\cdot}75}}}{\cancel{1963{\cdot}5}} \times 7}{\underset{11}{\cancel{22}}} = r^2 = \underline{624{\cdot}75}.$$

$$\therefore \sqrt{624{\cdot}75} = 25'' \therefore d = 50 \text{ inches nearly (as before).}$$

Note.—It is often of importance in such questions to get the answer quickly and near enough to the truth without going through an elaborate series of multiplications and divisions by long numbers (such as multiplying or dividing by 3·1416). We consequently recommend the above method of cancelling by easy stages. If the student should happen to have a logarithm book, and know how to use the tables, he will find that he can work such questions very easily and quickly; but he must remember that logarithm books are not usually permitted in written examinations.

EXAMPLE VIII.—Steam is admitted into the cylinder of a steam engine whose diameter is 2 feet 4 inches, at a pressure of 50 lbs. per square inch. What is the total pressure on the piston, if the diameter of the piston-rod on the side upon which the steam is admitted be 3 inches?



Side View *End View*

In this question, the first thing to be done is to find the nett area upon which the steam acts; in other words, we have to subtract the cross area of the piston-rod from the cross area of the cylinder.

Cross area of cylinder $= \pi r_1^2 = \frac{22}{7} \times 14 \times 14 = 615{\cdot}75$ sq. in.

Cross area of piston-rod $= \pi r_2^2 = \frac{22}{7} \times 1{\cdot}5 \times 1{\cdot}5 = \quad 7{\cdot}07$ „

The nett area $= \pi r_1^2 - \pi r_2^2$ . . . . $= \underline{608{\cdot}68}$ „

$\therefore$ 50 (lbs.) × 608·68 (square inches) = 30,434 lbs. total pressure.

5. To Find the Surface Area or Envelope of a Sphere.

DEFINITION.—*A sphere is a perfectly round body, every point on the surface of which is equidistant from the centre.*

RULE.—The surface of a sphere is equal to the concave surface of the circumscribing cylinder; consequently,

Multiply the square of the diameter by 3·1416, or by $\frac{22}{7}$.

$$\text{Or, area} = \pi d^2 = 4\pi r^2.$$

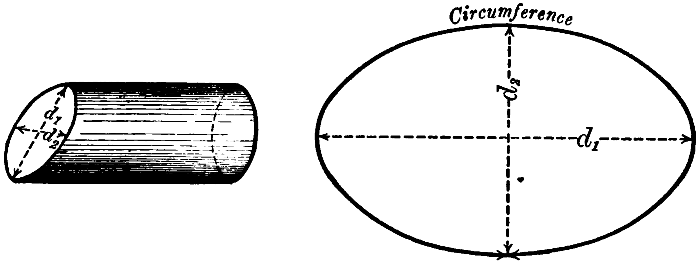
EXAMPLE IX.—A spherical cast-iron ball, 8 inches diameter, is used as a counter-weight to a reversing lever, and, in order to keep it bright and clean, it is desired to electro-plate it with nickel plating, which costs 5*s.* per square foot. What will be the cost?

Surface area of sphere $= \pi d^2 = \frac{22}{7} \times \dot{\cdot 6}^2$ (ft.) $= 1{\cdot}38$ square feet.

$\therefore$ cost $= 5$ (*s.*) × 1·38 (square feet) = 6·9*s.* = 7*s.* nearly.

6. To Find the Circumference of an Ellipse.

DEFINITION.—*An ellipse is a plane curve formed by cutting a right circular cylinder by a plane inclined to the axis, which plane does not meet the base of the cylinder.*



Elliptical forms are frequently used by engineers for manhole doors, elliptical flues, &c.

RULE.—*Multiply* π *or* (3·1416) *by half the sum of the two diameters* $\left(\frac{d_1 + d_2}{2}\right)$; *the product will be the circumference nearly.*

$$\text{Or, circumference} = \pi\left(\frac{d_1 + d_2}{2}\right).$$

The superficial area or envelope of an elliptical cylinder is therefore $= \pi\left(\frac{d_1 + d_2}{2}\right) \times l$, where l is the length of the axis of the cylinder.

7. **To Find the Area of an Ellipse:—**

RULE.—*Multiply* $\frac{\pi}{4}$ *or* (·7854) *by the product of the two diameters,* $(d_1 \times d_2)$.

$$\text{Or, area} = \frac{\pi}{4}(d_1 \times d_2).$$

EXAMPLE X.—What is the area in square feet of the elliptical manhole doors of the s.s. *St. Rognvald*, whose longer diameter is 16 inches and shorter diameter is 12 inches?

$$\begin{aligned} \text{Area} &= \frac{\pi}{4}(d_1 \times d_2) \\ &= \cdot 7854 (1 \cdot \dot{3} \text{ foot} \times 1 \text{ foot}) \\ &= \cdot 7854 \times 1 \cdot \dot{3} = 1 \cdot 0445 \text{ square feet.} \end{aligned}$$

LECTURE II.—QUESTIONS.

1. A furnace door is of this shape and size, 

(2 feet long, 1 foot high at ends, and 1 foot 3 inches high in middle). Find its area in square feet. *Ans.* 2·25 sq. ft.

2. Find the area in square inches, by Simpson's rule, of the diagram illustrated at p. 114. *Ans.* 1050 sq. ins. (taking pressures marked as inches).

3. Referring to the diagram at p. 114, let the length of the figure be 2 feet, and the various ordinates, 65, 60, 46, . . . 17, represent inches. Find the area of the figure in square feet. *Ans.* 7·25 sq. ft.

4. A cylinder is 53″ diameter. Find the circumference. *Ans.* 166·5 inches.

5. What is the girth of a circular steam pipe whose diameter is 10½″? *Ans.* 32·98 inches.

6. The girth of a circular furnace tube, measured by a string, is found to be 3′ 6″. What is its radius? *Ans.* 6·69 inches.

7. The inside diameter of a furnace tube is 3′ 1½″, and the thickness of the metal is ½″. Find the outside circumference. *Ans.* 10·08 feet, or 10′ 0⅞″ $\frac{1}{16}$ full.

8. The funnel of a steamship is 5 feet diameter, and is made of three plates in girth; the lap of each plate is 1¾ inch. Find the width of each plate. *Ans.* 5·38 feet.

9. The outside diameter of the flange of a cylinder-cover is 6 feet; the pitch between the bolt-holes is to be 6⅝ inches. How many bolts will be required if the pitch-circle be 2½ inches from the outside edge of the flange? Plot this out to scale. *Ans.* 33 bolts.

10. What is the area of the rubbing surface in a cylinder, the diameter of the piston being 52 inches and the stroke 3 feet. *Ans.* 40·84 sq. ft.

11. How many square feet of iron plate are there in a ship's circular funnel, 4′ 6″ diameter and 26 long? *Ans.* 367·5.

12. The diameter of a cylinder is 25·5 inches. What is its area? *Ans.* 510·7 square inches.

13. The area of a cylinder is 2002·96 square inches. What is its radius? *Ans.* 25¼ inches.

14. The cylindrical boilers of the s.s. *St. Rognvald* are each, say, 15 feet internal diameter and 10′ 3″ long inside. Find the total pressure on the back end and on the barrel of the boiler with 90 lbs. pressure of steam per square inch. *Ans.* 2,290,226·4 lbs. on back end, 6,259,952 on barrel.

15. The diameters of the high and low pressure cylinders of the s.s. *St. Rognvald* (Lecture XX.) are 36″ and 70″. The diameters of the piston-rods are 6½″ below and 4½″ above the pistons in each case. What is the effective area for the steam-pressure to act on, in each case? *Ans.* H.P. cyl. 984·68 square inches below and 1001·97 above; L.P. cyl. 3815·28 square inches below, and 3832·56 above.

16. An elliptical manhole is 16½″ longer diameter, and 12½″ shorter diameter. What is the circumference and area of the whole in square feet? The wrought-iron strengthening ring, which is flush all round with the manhole on the inside, is 4″ broad. What is its outer circumference and its superficial area? *Ans.* O^{ce} = 3·73 ft., area = 1·08 sq. ft. Outer O^{ce} = 5·825 ft. superficial area = 1·6 sq. ft.

LECTURE III.

CONTENTS.—Table of Weights and Measures—Table of Specific Gravities of Metals, Coals, Woods, &c.—Volumes of a Rectangular Solid or a Tank, Parallelopiped, Prism, Cylinder, Cone, Frustrum, and a Sphere—Surface of a Cone and a Frustrum—Examples.

HAVING explained and worked out a series of examples on Linear and Superficial or square measure in the two first lectures, we are now prepared to deal with the capacities or volumes or contents of solids, and their weights. We, therefore, begin by giving a few of the most useful and common tables of weights and measures used by British mechanical engineers.

A.—TABLE OF WEIGHTS AND MEASURES.

1 ton	= 20 cwt. = 2240 lbs. = 35,840 oz.
1 cubic foot	= { 1728 cubic inches 0·037 = $\frac{1}{27}$ cubic yard 6·2355, or roughly, 6·25 gallons
1 gallon	= { 277¼ cubic inches 0·16 cubic foot 4 quarts = 8 pints = 32 gills
Fresh water .	{ 1 cubic foot weighs 62·5 lbs. = 1000 oz. 1 gallon ,, 10 ,, 35·84 cubic feet weigh 1 ton
Salt water .	{ 1 cubic foot weighs 64 lbs. 1 gallon ,, 10¼ ,, 35 cubic feet weigh 1 ton * = 218½ gallons

B.—TABLE OF SPECIFIC GRAVITIES.†

RULE 1.—*To find the weight of a* CUBIC INCH *of any of the substances mentioned in this Table, multiply its specific gravity by* ·036, *the weight of a cubic inch of fresh water.*

RULE 2.—*To find the weight of a* CUBIC FOOT *of any of the*

* This number is used for finding the displacement of a vessel in sea-water or the weight of sea-water ballast.

† Specific gravity is the ratio of the weight of a given bulk of a given substance to the weight of the same bulk of pure water, at a standard temperature (62° Fahr. in Great Britain). The above table of specific gravities gives only rough averages, and, therefore, must not be adopted for scientific or very exact calculations.

substances mentioned in this Table, multiply its specific gravity by 62·5, *the weight of a cubic foot of fresh water*—the specific gravity of water being taken as = 1.

METALS.		COAL.	
Name.	Sp. Gravity.	Name.	Sp. Gravity.
Cast iron	7·1	Scotch	1·26
Wrought iron	7·7	Welsh	1·3
Steel, mild	7·7 to 7·8	Newcastle	1·25
,, hard	7·85	Lancashire	1·27
Copper, cast	8·6		
,, hard wire or sheet	8·8	WOODS, ETC.	
Brass, cast hard	8·4	Yellow pine	0·66
Lead	11·4	Mahogany, Spanish	0·85
Mercury	13·58	Oak	·7 to 1·0
Steam at atmo.-pressure	·000608		
Oil (whale)	·92		

EXAMPLE I.—Find the weight of a cubic inch and of a cubic foot of cast iron.

The specific gravity of cast iron = 7·1.

∴ the weight of a cubic inch = ·036 × 7·1 = ·2556 lb., roughly ¼ lb.,

and the weight of a cubic foot = 62·5 × 7·1 = 443·75 lbs.

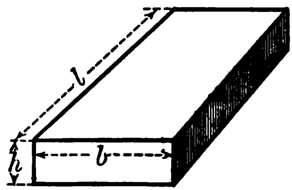
Note.—Students should work out the weights of a cubic inch and of a cubic foot for each of the above substances; and try to remember in round numbers their values. Thus, *e.g.*, there can be no difficulty in remembering that a cubic inch of cast iron weighs about ¼ lb., and a cubic foot about 444 lbs.

1. To Find the Volume of a Rectangular Solid or Parallelopiped.

DEFINITIONS.—*A parallelopiped is a solid bounded by six parallelograms, of which every opposite two are equal and in parallel planes.* It is termed rectangular when the six bounding parallelograms are *rectangular*, and *oblique* when they are not. A common brick is a good example of a rectangular solid.

A CUBE *is a rectangular solid bounded by six equal squares.*

A PRISM *is a solid bounded by plane rectilineal figures, of which two are equal and in parallel planes, and the rest are parallelograms.*



RULE.—*Multiply the length, l, by the breadth, b, and by the height, h.*

EXAMPLE II.—A tank for ship use is 4 feet long and 4 feet broad. What quantity of fresh water in gallons and in lbs, will it contain for every foot of height or depth?

$$\text{The capacity} = l \times b \times d$$
$$= 4' \times 4' \times 1'$$
$$= 16 \text{ cubic feet.}$$

Referring to the Table at the beginning of this lecture, we find that there are 62·5 lbs. of fresh water to the cubic foot, or 6·25 gallons:

$$\therefore 16 \times 6{\cdot}25 = 100 \text{ gallons} = 1000 \text{ lbs.}$$

EXAMPLE III.—An oil-tank measures 2′ 6″ by 1′ 6″ by 2′ 0″. How many gallons and pounds of oil will it hold?

$$\text{The capacity} = l \times b \times d$$
$$= 2{\cdot}5' \times 1{\cdot}5' \times 2'$$
$$= 7{\cdot}5 \text{ cubic feet.}$$

But every cubic foot contains 6·25 gallons:

$$\therefore 7{\cdot}5 \text{ (cubic feet)} \times 6{\cdot}25 \text{ (gallons)} = 46{\cdot}875 \text{ gallons.}$$

And since the specific gravity of oil (*see* Table) is ·92, we have by proportion—

$$\begin{array}{l} 1 \text{ (sp. gr. water)} : {\cdot}92 \text{ (sp. gr. oil)} :: 62{\cdot}5 \text{ (lbs.)} : x \\ 1 \text{ (cubic foot)} \quad : 7{\cdot}5 \text{ (cubic feet)} \end{array}$$

$$\therefore x = \frac{{\cdot}92 \times 62{\cdot}5 \times 7{\cdot}5}{1 \times 1}$$
$$= 431{\cdot}25 \text{ lbs. of oil.}$$

EXAMPLE IV.—A bar of wrought iron of rectangular section is 4′ long by 4″ broad by 3″ deep. Find its weight.

$$\text{The volume} = l \times b \times d$$
$$= 48'' \times 4'' \times 3''$$
$$= 576 \text{ cubic inches.}$$

Referring to the Table, we see that the specific gravity of wrought iron is 7·7, and that a cubic inch of water weighs ·036 lbs.

$$\begin{array}{l} \therefore 1 \text{ (sp. gr. water)} : 7{\cdot}7 \text{ (sp. gr. iron)} :: {\cdot}036 \text{ (lbs.)} : x \\ \quad 1 \text{ (cubic inch)} \quad : 576 \text{ (cubic inches)} \end{array}$$

$$\therefore x = \frac{7{\cdot}7 \times {\cdot}036 \times 576}{1 \times 1} = 159{\cdot}66 \text{ lbs., say } 160 \text{ lbs.}$$

2. To Find the Volume of *any* Parallelopiped, Prism, or Cylinder.

RULE.—*Multiply the area of the base by the length, l, or height, h.*

EXAMPLE V.—The cylinder of a steam engine is 36″ diameter, and the stroke of the piston is 4′; what is the displacement or volume of steam in cubic feet in the cylinder at end of stroke? Also, what is the weight of this steam if 1 cubic foot of steam at atmospheric pressure weighs ·038 lb.?

Volume = area of cylinder × length of stroke.

$$= \pi r^2 \times l$$
$$= 3{\cdot}1416 \times 1{\cdot}5' \times 1{\cdot}5' \times 4'$$
$$= \underline{28{\cdot}2744} \text{ cubic feet.}$$

$$\text{Or } = \frac{\pi}{4} d^2 \times l$$
$$= {\cdot}7854 \times 3' \times 3' \times 4'$$
$$= \underline{28{\cdot}2744} \text{ cubic feet.}$$

$\therefore$ 1 (cubic foot) : 28·27 (cubic feet) :: ·038 (lb.) : x lb.

$$x = \frac{28{\cdot}27 \times {\cdot}038}{1} = 1{\cdot}074 \text{ lb. of steam.}$$

EXAMPLE VI.—What is the weight of the brass liner of an air-pump, the diameter of the bucket being 23 inches, the length of liner 17 inches, and its thickness ½ inch?

First: Find the area of a flat ring 23 inches internal diameter and ·5 inch broad, or 24 inches external diameter.

Let d_1 = the larger diameter, and d_2 = the smaller one.

$$\text{Then} \quad \frac{\pi}{4}(d_1^2 - d_2^2) = \text{area of ring}$$
$$= {\cdot}7854(24^2 - 23^2)$$
$$= 36{\cdot}9 \text{ square inches.}$$

Second: Find the volume of this brass tube in cubic inches.

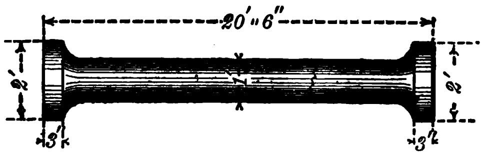
$$\text{Volume} = \text{area of ring} \times \text{length}$$
$$= 36{\cdot}9 \text{ (square inches)} \times 17''$$
$$= 627{\cdot}3 \text{ cubic inches.}$$

Third: Find the weight, by referring to the table of specific gravities at the beginning of this lecture (where we see that brass is 8·4), and by proportion. Thus—

1 (sp. gr. of water) : 8·4 (sp. gr. of brass) :: ·036 (lb.) : x lbs.
1 (cubic inch) : 627·3 (cubic inches)

$$\therefore x = \frac{8{\cdot}4 \times {\cdot}036 \times 627{\cdot}3}{1 \times 1}$$
$$= 190 \text{ lbs. (nearly).}$$

EXAMPLE VII.—A plain, solid tunnel-shaft for a steam-ship is of the dimensions shown by the following sketch, and is made



of mild steel. Find its volume and its weight, neglecting fillets and bolt-holes.

First: Find volume of shank. This consists of a solid cylinder, 20 feet long and 1 foot in diameter.

$$\text{Volume} = \pi r^2 l = 3{\cdot}1416 \times {\cdot}5'^2 \times 20' = \underline{15{\cdot}7} \text{ cubic feet.}$$

$$\text{Or} = \frac{\pi}{4} d^2 l = {\cdot}7854 \times 1'^2 \times 20' = \underline{15{\cdot}7} \text{ cubic feet.}$$

Second: Find the volume of one flange, and multiply this by 2, since there are two flanges (one at each end): and then add this volume to that of the shank.

$$\text{Volume of flange} = \pi r^2 l = 3{\cdot}1416 \times 1'^2 \times {\cdot}25 = \underline{{\cdot}7854} \text{ cubic feet.}$$

$$\therefore \text{ volume of 2 flanges} = {\cdot}7854 \times 2 = \underline{1{\cdot}5708} \text{ cubic feet.}$$

Volume of shank	= 15·7 cubic feet	
" 2 flanges	= 1·57	"
Total volume	= 17·27	"

Third: Refer to the table of specific gravities for the specific gravity of mild steel, and we find it to be 7·8; consequently, by proportion—

1 (sp. gr. water) : 7·8 (sp. gr. steel) :: 62·5 (lbs.) : x lbs.
1 (cubic foot) : 17·27 (cubic feet)

$$\therefore x = \frac{7{\cdot}8 \times 62{\cdot}5 \times 17{\cdot}27}{1 \times 1} = 8420 \text{ lbs. (nearly)}$$

$$= 3 \text{ tons } 15 \text{ cwt. } 20 \text{ lbs.}$$

In our last Lecture we did not refer to the surface area of a cone, or the frustrum of a cone. We shall now state how to find them, as well as their volumes, but without giving any arithmetical examples, as these figures do not frequently occur in the forms of parts in steam engines. If examples should be desired, they can easily be given by the teacher, or found by students themselves. Probably the time will be fully occupied working out a few of the more useful examples at the end of this and the preceding Lectures.

3. To Find the Area of the Curved Surface of a Right Circular Cone.

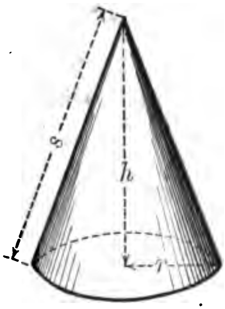
DEFINITION.—*A cone is a solid, produced by turning a right-angled triangle round one of the sides which contain the right angle, this side remaining as the fixed axis.*

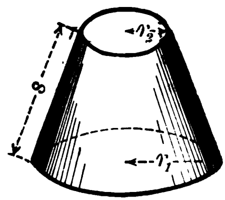
RULE.—*Multiply the circumference of the base* ($2\pi r$) *by the slant height of the cone* (s), *and take half the product.*

$$\text{Or, surface area} = \frac{2\pi r s}{2} = \pi r s.$$

The curved surface of a right circular cone is the same as the area of a sector of a circle with radius equal to the slant side, s.

$\therefore$ 360° : degrees between radii of sector :: area of circle : area of sector.





4. To Find the Area of the Curved Surface of a Frustrum of a Right Circular Cone.

DEFINITION.—*A frustrum of a cone is the lower portion of the cone which is left after removing the top piece.*

RULE.—*Multiply the sum of the circumferences of the two ends of the frustrum* $2\pi(r_1 + r_2)$ *by the slant height of the frustrum,* s, *and take half the product.*

$$\text{Or, surface area} = \frac{2\pi(r_1 + r_2)s}{2} = \pi(r_1 + r_2)s.$$

5. To Find the Volume of a Pyramid or of a Cone.

RULE.—*Multiply the area of the base by the height, and divide the product by* 3.

$$\text{Formula for volume of a right cone} = \frac{\pi r^2 h}{3}.$$

6. To Find the Volume of a Frustrum of a Pyramid or of a Cone.

RULE.—*To the areas of the two ends add the square root of their product; multiply the sum by the height of the frustrum, and divide the product by* 3.

Volume of frustrum of right cone $= \left[\pi(r_1^2 + r_2^2) + \sqrt{}\pi(r_1^2 + r_2^2)\right]\frac{h}{3}$.

Or, if we know the height, h_1, of the complete cone, as well as the height, h_2, of the top cone cut away, then the difference between the volume of the complete cone and that of the smaller part cut away leaves the volume of the frustrum.

Thus:—

$$\text{Volume of frustrum} = \frac{\pi r_1^2 h_1}{3} - \frac{\pi r_2^2 h_2}{3}$$

$$\text{,, \quad ,,} \quad = \pi\left(\frac{r_1^2 h_1 - r_2^2 h_2}{3}\right).$$

7. To Find the Volume of a Sphere.

RULE —*Take* $\frac{4}{3}$ *of the area of the circumscribing circle, and multiply this by the radius.*

$$\text{Or, volume} = \frac{4}{3}\pi r^2 \times r = \frac{4}{3}\pi r^3.$$

For the purpose of having a combined ready reference to the different formulæ for the various rules given in the preceding lectures, we now arrange them in the form of tables, adopting the same notation throughout.

NOTATION USED.

l for Length	d for Diameter
b „ Breadth	π „ 3·1416 or $\frac{22}{7}$
h „ Height	$\frac{\pi}{4}$ „ ·7854
s „ Side	$\perp$ „ Perpendicular
n „ No. of parts	
r „ Radius	

LENGTHS.

Circumference of a Circle $= \pi d = 2\pi r$

„ of an Ellipse $= \pi\left(\frac{d_1+d_2}{2}\right)$

SURFACE AREAS.

A Square	$= l^2$
An Oblong	$= l \times b$
A Parallelogram	$= l \times \perp, b$
A Triangle	$= l \times \perp, \frac{h}{2}$
A Trapezoid	$= \left(\frac{l_1+l_2}{2}\right)\perp h$
A Trapezium	$= l\left(\frac{h_1+h_2}{2}\right)$
A Rectilineal	Sum of parts
A 4-sided Figure, one side curved .	$= \left(\frac{A+2B}{2}\right)\frac{L}{n}$
Simpson's Rule	$= \left(\frac{A+4B+2C}{3}\right)\frac{L}{n}$
A Cylinder	$= 2\pi rl$
A Cone and a Sector . . .	$= \pi rs$
A Frustrum do.	$= \pi(r_1 + r_2)s$
A Circle	$= \pi r^2$
A Sphere	$= 4\pi r^2$
An Ellipse	$= \frac{\pi}{4}(d_1+d_2)$

VOLUMES.

A Rectangular Solid $= l \times b \times h$	Cone . . . $= \frac{\pi r^2 h}{3}$
A Cylinder . . $= \pi r^2 h$	Pyramid . . $= \frac{\text{Area base} \times h}{3}$
Any Prism . . $=$ Area base $\times h$	Sphere . . $= \frac{4}{3}\pi r^3$

Frustrum . . $= \frac{\text{Area of ends} + \sqrt{\text{Area of ends}}}{3} \times \perp h$

Lecture III.—Questions.

1. Find the weights of a cubic inch and of a cubic foot of (1) cast iron; (2) wrought iron; (3) steel, mild; (4) steel, tempered. *Ans.* (1) ·255; 443·75; (2) ·277; 481·25; (3) ·277; 481·25; (4) ·28; 490·6 lbs.

2. Find the weight of a cubic inch and of a cubic foot of (1) copper, cast; (2) copper, hard wire; (3) brass, cast; (4) lead; (5) mercury. *Ans.* (1) ·3; 537·5; (2) ·31; 550; (3) ·3; 525; (4) ·41; 712·5; (5) ·49; 848·75 lbs.

3. Find the weight of a cubic foot; also how many cubic feet make up a ton weight in the case of (1) Scotch, (2) Welsh, (3) Newcastle, (4) Lancashire coals. *Ans.* (1) 79; 28·4; (2) 81; 27·5; (3) 78; 28·8; (4) 79.5; 28·2.

4. Find the weight of a cubic foot of steam at atmospheric pressure from the Specific Gravity Table. *Ans.* ·038 lb.

5. How many cubic inches and cubic feet are there in a rectangular box which is 2 feet long, 18 inches wide, and 1 foot deep? *Ans.* 5184 cubic inches; or 3 cubic feet.

6. What is the capacity of a rectangular tank 3′ deep, 15′ long, 27″ wide? *Ans.* 101·25 cubic feet.

7. A tank 4 feet square in horizontal section is sounded by a rod, and there is found to be a depth of 3′ 3″ of water in it. How many pounds and gallons of fresh water are there in the tank? *Ans.* 3250 lbs.; 325 gallons.

8. You are supplied with 100 gallons of oil. What will be its weight, and its bulk in cubic feet? *Ans.* 920 lbs.; 16 cubic feet.

9. A wrought-iron cap for the cover of a marine crank-shaft bearing is 16″ by $12\frac{1}{2}$″ by $3\frac{1}{2}$″. Find its weight. *Ans.* 194 lbs.

10. What weight of coal in tons will a bunker hold which is 18′ by 5′ 6″ by 12′, allowing 45 cubic feet to the ton for coals stored in this way? *Ans.* 26·4 tons.

11. How many cubic feet of steam will be required per minute for a steam-engine cylinder 60″ diameter; steam being cut off at 1′ of stroke when the engine is making 90 strokes per minute? *Ans.* 1767.

12. In the last question, suppose the engine develops 60 horse-power with steam supplied at 50 lbs. pressure, which weighs ·12 lb. per cubic foot. What weight of steam would be required per hour per horse-power? *Ans.* 212 lbs.

13. Find how many cubic feet of steam will exhaust from a steam-engine cylinder per hour, and also the weight of this steam at atmospheric pressure (*see* Sp. Gr. Table), if the diameter of the cylinder be 60″, stroke 6 feet when the engine makes 90 strokes per minute. *Ans.* 636,174 and 24,175.

14. Find the weight of a wrought-iron shaft of the dimensions and shape given in Example VII. of this lecture. *Ans.* 3 tons 14 cwt. 24 lbs.

15. Find the weight of a circular plate of wrought iron 3 feet in diameter and $\frac{5}{8}$″ $\frac{1}{16}$ thick. *Ans.* 194·5 lbs.

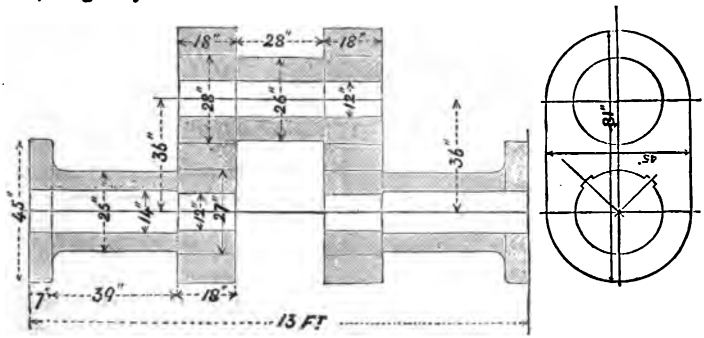
16. A feed-pump is 4″ diameter and 14″ stroke, but it is only $\frac{3}{4}$ full each stroke. Find the number of gallons and weight of water which it pumps into a boiler when making 72 strokes per minute. *Ans.* 34·36 gallons per minute; or, 343·6 lbs.

17. Find the weight of the brass liner to an air-pump which is 24″ internal diameter, 24″ long, and $\frac{5}{8}$″ thick. *Ans.* 351·2 lbs.

18. Find the weight of the rim of a cast-iron fly-wheel of rectangular parallelogram section outside diameter 6′, inside diameter 4′ 6″, breadth 9″. *Ans.* 4116·6 lbs.

19. Find the total weight of the crank-shaft of the s.s. *City of Rome*. There are three cranks of the shape and dimensions given in the following

figure, and they are made of Whitworth's compressed steel, the specific gravity of which may be reckoned at 7·8. Sketch each separate part in your exercise-book before your calculation of the volume thereof, and sum up the whole in a neat table. *Ans.* Weight reported by owners to be 63 tons, weight by careful calculation from this figure 62½ tons.



ONE CRANK OF S.S. "CITY OF ROME.'

20. Find the weight of a spherical cast-iron ball (used as a safety-valve balance weight) which is 10" inches in diameter. *Ans.* 131·4 lbs.

LECTURE IV.

CONTENTS.—Temperature—Thermometers—Pyrometers.

It is necessary, at the very outset of this section of our subject, to clearly understand what is meant by the different expressions:

1. The *temperature* of a body.
2. The *quantity of heat* in a body, and the *unit of heat*.
3. The *capacity for heat*, and the *specific heat* of a body.

Temperature.—*The temperature of a body is its thermal state considered with reference to its power of communicating heat to other bodies* (MAXWELL).

Two bodies are said to be at the *same* temperature if, when placed in thermal communication, there is *no* tendency to the transfer of heat between them; if, however, one of them loses heat, and the other gains heat, that body which *gives out* heat is said to have a *higher* temperature than that which receives heat.

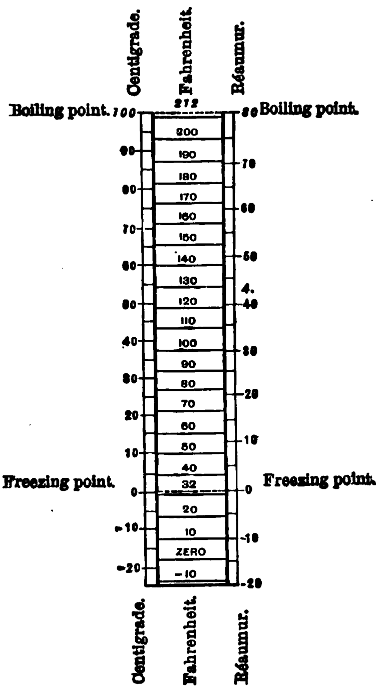
Temperature, therefore, indicates the *quality* or *condition* of the heat in bodies, and is capable of greater or less intensity according to circumstances. It is measured by Thermometers and Pyrometers.

Thermometry.—Thermometry is the method of ascertaining temperatures, or the intensities of heat. The action of thermometers is based on the change of volume to which bodies are subject with a change of temperature. Air, water, spirit, and mercurial thermometers are severally used under different circumstances, but the mercurial thermometer is the one most commonly employed by engineers. The mercurial thermometer consists of a stem or tube of glass, formed at one end into a bulb, to contain the mercury which expands into the tube (see left-hand figure). If the stem be of uniform bore, the expansion of the mercury being practically equal for equal increments of temperature, it follows that, if the scale be uniformly graduated, the divisions will indicate equal increments of temperature.

It was early ascertained that the freezing and the boiling points of water at the normal pressure of the atmosphere (viz., 14·7 lbs. on the square inch) were constant temperatures, and advantage is taken of this physical property in order to graduate thermometers. The interval between these two fixed temperatures is

in the case of the Fahrenheit thermometer (the one commonly used by English engineers) divided into 180 equal parts, termed degrees; in the case of the Centigrade, or standard French thermometer, into 100 equal parts; and in the Réaumur, or the thermometer used in Germany, Russia, &c., into 80 parts. The Centigrade thermometer is now used as the standard thermometer by all the best physicists, and students should familiarize themselves with readings taken by it, as well as with constants and tables to that scale. The comparative scales (see central figure) will render the corresponding points and divisions on the three kinds of thermometers clear to the student.

Ordinary Mercurial Thermometer.



Engineer's Thermometer with Wooden Handle, and Frame for taking Temperature of Water issuing from a Tap, &c.

For comparative tables of Fahrenheit, Centigrade, and Réaumur thermometers, see the author's advanced text-book on *Steam and Steam Engines.*

Engineers' Thermometers.

The following three figures illustrate the construction of a thermometer with its protecting case, as adopted by engineers for finding the temperature of steam in an engine-cylinder, or the condensing water and condensed steam in a condenser, &c.

Fig. 1 shows the glass tube and scale; Fig. 2 the glass tube, surrounded by its protecting case, which is screwed into the position where the temperature has to be ascertained. Fig. 3 shows the application of an iron bath, B, which is filled with mercury, and fixed by a hexagon nut, D, to the upper or projecting part. The iron bath, B, is represented partly in section, showing the mercury bulb, C. The mercury in the bath quickly arrives at the same temperature as the water or the steam surrounding it, and slight variations in temperature are easily detected. A small quantity of chemical liquid, called "valvoline," placed on the top of the mercury in the iron bath, is useful for protecting the brass at E from the action of the mercury.

It is certainly a great inconvenience to have to convert readings taken in one scale to that of another, but students should thoroughly master the simple proportion that exists between the different scales, so as to be independent of conversion tables.

Since the temperature of freezing water, or melting ice, is marked on the different scales as follows—

Fig. 1.

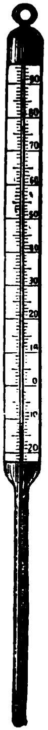
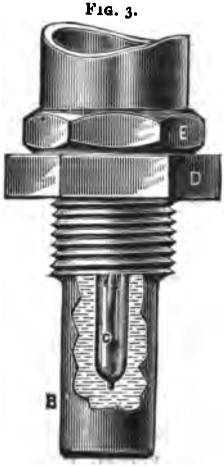


Fig. 2.

Fig. 3.



Schäffer and Budenberg's Thermometers, for taking the Temperature of Steam, Water, and Fuel Economizers, &c.

Fah.	Cent.	Réau.
32°	0°	0°

and the boiling point of water—

Fah.	Cent.	Réau.
212°	100°	80°

we obtain the proportion that exists between the scales by subtracting the freezing from the boiling points, thus—

Fah.	Cent.	Réau.
180°	100°	80°

Now, to convert a reading observed on the one scale to its corresponding value on either of the others—

Let F = Temperature Fahrenheit
C = „ Centigrade
R = „ Réaumur.

Then we observe that we must *subtract* 32° from the Fah. scale *before* applying the above proportion in converting it to the Cent. or to the Réau., but *add* 32, *after* applying the above proportion, in converting either the Cent. or the Réau. into the Fah. scale, as follows:—

$$(F-32) : C : R :: 180 : 100 : 80$$
$$\text{or as } 9 : 5 : 4$$

$$\therefore \text{ Degrees } C = \frac{(F-32)\,5}{9}$$

$$\text{„} \quad R = \frac{(F-32)\,4}{9}$$

$$\text{„} \quad F = \frac{C \times 9}{5} + 32$$

$$\text{„} \quad F = \frac{R \times 9}{4} + 32$$

EXAMPLES.—Suppose the temperature of the feed-water for a boiler is 102° Fah., find the corresponding temperature on the Cent. and Réau. scales:

By proportion— $9 : 5 :: (F - 32) : C$

$$\therefore C = \frac{F - 32)\,5}{9} = \frac{(102 - 32)\,5}{9} = \frac{70 \times 5}{9} = \frac{350}{9} = 38^\circ{\cdot}8 \text{ Cent.}$$

Again— $9 : 4 :: (F - 32) : R$

$$\therefore R = \frac{(F - 32)\,4}{9} = \frac{(102 - 32)\,4}{9} = \frac{280}{9} = 31^\circ{\cdot}1 \text{ Réau.}$$

Suppose the temperature of the hot well is 80° Cent., what is this on the Fah. and Réau. scales?

By proportion— $5 : 9 :: C : (F - 32)$

$$\therefore F = \frac{C \times 9}{5} + 32 = \frac{80 \times 9}{5} + 32$$

$$= \frac{720}{5} + 32 = 144 + 32 = 176^{\circ} \text{ Fah.}$$

Again— $5 : 4 :: C : R$

$$\therefore R = \frac{C \times 4}{5} = \frac{80 \times 4}{5} = 64^{\circ} \text{ Réau.}$$

Note.—We shall treat of the "absolute zero" of the thermometric scale when we come to pressure and volume of gases.

Pyrometers are usually employed to measure temperatures above the boiling-point of mercury (about 676° Fah.); for example, the temperature of a furnace, or the waste gases in a chimney.

Pyrometric estimations are of four classes:—

First. Those of which the indications are based upon the change of the dimensions of a particular body, solid or gaseous—the pyrometer proper.

Second. Those based on the quantity of heat imparted to a known weight of water, by immersing in the water a body of known weight, that has previously been raised to the temperature which it is required to determine.

Third. Those which are based on the melting points of metals and metallic alloys.

Fourth. Those which are based on the well-known fact that the pressure of saturated steam (that is to say, of steam remaining in direct communication with the liquid from which it is generated) corresponds to the temperature of the liquid and the steam. We shall describe this form in Lecture XI., when we come to discuss Regnault's tables and pressure-gauges.

1. *Wedgewood's pyrometer*, invented in 1782, belongs to the *first* class. It is founded on the property possessed by clay, of contracting at high temperatures. He made a tapered groove of metal, so arranged, that the clay, when rolled or pressed into the form of a small cylinder, just fitted, or entered the groove, if raised to a dull red heat, but, as its temperature was increased, it shrank and could be slipped further along the tapered groove. He divided the tapered groove into degrees Fah. Unfortunately, it has been found that the contraction of the clay is not exactly proportional to the increase of temperature, and consequently the use of

this form of pyrometer is confined to rough and ready experiments.

Daniell's pyrometer depends on the expansion of a metal bar enclosed in a black-lead case. This case is drilled out 7·5 inches deep to a diameter say of ·3 inch. A rod of platinum, or of soft iron, a little less than the bore, and about an inch shorter, is inserted into the black-lead case, and surmounted by a porcelain index. When the whole instrument is placed in a furnace, the greater expansion of the metal as compared with that of the black-lead, presses forward the index, which remains at the furthest position, so that, when removed, it registers the highest temperature to which it was subjected. Pyrometers constructed on this principle are not very accurate.

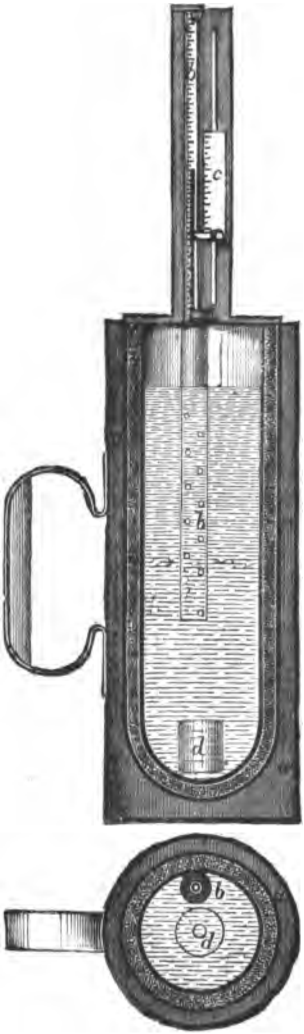
2. *Wilson's water pyrometer* is one of the best known instruments for the *second* means of estimating higher temperatures. The inventor places in the fire or heated chamber, a known weight of platinum, in the form of a thin cylinder, until it has assumed the temperature thereof. He then takes it out, and plunges it quickly into a vessel containing water exactly twice the weight of the platinum, and observes the rise in temperature of the water; when the temperature of the chamber or fire is found by the following simple rule:—"*Multiply the rise in temperature of the water by a constant*, 62, *and add the final temperature of the water.*" The way in which this rule is found will be fully explained in our next lecture, when we come to treat of specific heat. In Siemens' water pyrometer, copper cylinders are used instead of platinum; the principle and method of using it are as follows:—

Siemens' Water Pyrometer.—This pyrometer, which is shown in the following sketch in vertical and horizontal sections, consists of two cylindrical copper vessels having an air space, *a*, between them. The inner vessel is constructed (with a view to prevent radiation), of a double casing of copper with an intermediate packing of felt, and is of sufficient size to hold rather more than a pint of water.

A mercurial thermometer, *b*, is fixed against one side of the inner vessel and protected by a perforated tube. The upper half of the thermometer projects above the copper vessel and is graduated in the ordinary degrees, Fahrenheit or Centigrade, while by the side of it is a small brass sliding scale, *c*, graduated and figured with degrees of the same denomination as the thermometer.

Cylinders, *d*, of copper, iron, or platinum, are provided with each pyrometer, their size being accurately adjusted so that the capacity for absorbing heat between 0° and 100° C. is equal to one-fiftieth of that of the vessel and pint of water which it contains; as, however, this capacity (specific heat) increases with the

temperature, the divisions on the sliding scale expand with rise in temperature and in a different ratio for the three metals specified, thus necessitating a special sliding scale for each metal of which the cylinders are composed.



SIEMENS' WATER PYROMETER.

a, Air Space. *c*, Sliding Scale.
b, Thermometer. *d*, Metal Cylinder.

Instructions.—The temperature of a furnace, &c., is ascertained in the following manner:—

A pint (0·568 litre or 34·66 cubic inches) of clean water is placed in the pyrometer vessel, and, after this has stood for a few minutes, the zero point of the sliding scale is set at the temperature indicated by the thermometer.

One of the metal cylinders, *d*, is then exposed from two to ten minutes to the heat to be measured, and allowed to remain in it until it has acquired its temperature. It is then quickly withdrawn and dropped into the water, the temperature of which rises gradually until a maximum is reached. *This rise of temperature, as indicated by the sliding scale, added to the temperature of the water at the end of the experiment, gives that of the furnace.*

The range of the pyrometer with copper and iron cylinders extends to 1000° C. or 1800° F., but with platinum cylinders to 1500° C. or 2700° F.

Cylinders of copper are found to be most suitable for general use in ascertaining the temperature of ordinary furnaces, while for very high temperatures those of platinum are alone available. Wrought-iron cylinders are sometimes employed, as they offer an advantage over those of copper in having a higher melting point, and being less liable to alteration in weight through loss by incrustation when plunged at

a high temperature into water. This advantage may, however, be considered as counterbalanced by the fact that copper is much less affected by the corrosive action of the gaseous products of combustion. For the reasons just given, platinum cylinders offer still further advantages.

3. The *third* method of estimating high temperatures, viz., that based on the melting-points of metals or metallic alloys, is applied by simply suspending in the heated chamber or furnace a small piece of metal, the melting point of which is known, and, if necessary, two or more pieces of different melting-points, so as to ascertain the temperature within certain limits, according to the pieces which are melted and those which remain unmelted. This is the rough and ready method most frequently adopted by workmen in iron, steel, and other smelting works.

LECTURE IV.—QUESTIONS.

1. Define the temperature of a body. What two natural phenomena have been employed to determine two points of reference in the scale of thermometers? And why?

2. State what is meant by "temperature." Describe how ordinary temperatures are measured. How many scales of temperature are there in common use in Europe? A thermometer registers 400° on the Fah.; find what it would indicate on a Cent. one. *Ans.* $204^{\circ}\cdot\dot{4}$ C.

3. Compare the Fah., Cent., and Réau. scales. A Cent. thermometer indicates 15°; show by proportion (in full) how you find what are the corresponding readings in the Fah. and Réau. scales. *Ans.* 59° F.; 12° R.

4. Zinc boils at 1204° F., mercury at 676° F.; change these readings to Cent. (show your work in full). *Ans.* 651° C., and 358° C.

5. Sketch and describe concisely the construction and action of Siemens' water pyrometer.

6. State the principles upon which four distinct classes of pyrometers are based.

LECTURE V.

CONTENTS.—Effects of Heat—Unit of Heat—Quantity of Heat—Capacity for Heat—Specific Heat—Table of Specific Heats of Substances.

Effects of Heat.—When heat is applied to a body it produces various effects. For example, in most instances it raises the temperature of the body, it generally alters its volume or its pressure, and in certain cases it changes the state of the body from solid to liquid, or liquid to gaseous.

Unit of Heat.—The standard unit now adopted in this country is called *The British Thermal Unit, and is the quantity of heat required to raise* 1 *lb. of water by* 1° *Fah., when at its maximum density,* i.e., *from* 39°·1 *to* 40°·1 *Fah.*

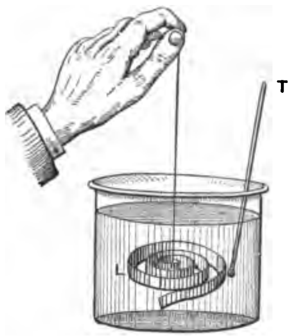
Quantity of Heat.—To be able to compare different quantities of heat, we must first fix on a standard or unit of heat. This is done by selecting a standard body, and noting the effects of heat upon it. For example, we might take a pound or other known weight of ice at its freezing or melting point, 32° F. or 0° C., and apply heat to it, until it all melts into water at the same temperature. This would give a definite standard, by which to compare other quantities of heat applied in the same way. Or, we might take a known weight of water at its boiling point, and apply heat to it until it all becomes converted into steam at the same temperature as the boiling water. This method is used in determining the quantity of heat obtained from different kinds of coal. We often find it stated, in connection with trials of steam boilers, that so many pounds of water were converted into steam at a certain pressure per pound of coal of a certain quality.

Capacity for Heat.—*The capacity for heat of a body (or its thermal capacity) is the number of units of heat required to raise that body one degree in temperature.*

Specific Heat.—*The specific heat of a body is the ratio of the quantity of heat required to raise that body one degree, to the quantity required to raise an equal weight of water one degree in temperature.*

To illustrate the above, take the case of lead. Weigh out 1 lb. of sheet lead, roll it into an open spiral, and attach it to a string. Now, dip the lead into a pot of freely boiling water until it has attained the temperature of the water. While this is going on

weigh out a pound of cold water, and ascertain its temperature with a thermometer; say it is 47° F. Then lift the lead from the boiling water, and, while holding it by the string in the steam rising from the water, allow all water to drop from it, and immerse it quickly in the cold water vessel, keeping it moving by means of the string, so as to bring it intimately into contact with every portion of the water, as shown in the annexed figure, where, L, is the lead, and, T, the thermometer. Observe the gradual rise in temperature of the water due to the heat passing from the lead, note the point at which it ceases to rise, and suppose that to be 52° F. We have thus ascertained data, from which we may calculate the relative capacities for heat of lead and water, if none of the heat from the lead was given to any other body than to the water.



Thus—The diminution in temperature of the lead from 212° to 52° = 160°; the increase in temperature of the water from 47° to 52° = 5°.

Now, since—

The Loss of Heat from the one substance = the Gain of Heat by the other.

∴ The heat from 1 lb. of lead falling 160° = the heat imparted to 1 lb. of water raised 5°;

$$\therefore \frac{\text{The units of heat in 1 lb. of lead}}{\text{The units of heat in 1 lb. of water}} = \frac{5}{160} = \frac{1}{32}.$$

In other words, the capacity for heat of lead is only $\frac{1}{32}$ part that of water, or the same quantity of heat would raise 1 lb. of lead through 32 times as many degrees as it would 1 lb. of water.

We may now apply the knowledge we have gained in this lecture to prove the rule for using Wilson's pyrometer, as given in our last lecture. Observe, Wilson plunges a known weight of platinum (for the sake of illustration, assume it to be 1 lb.) at an *unknown* temperature, $t_1°$, into double its weight of water (say 2 lbs.), and notes the rise in temperature, $t_2°$ to $t_3°$, from which he calculates the original temperature, $t_1°$, of the platinum, and, therefore, of the furnace from which it had been taken. Thus—

The Loss of Heat from the Platinum = the Gain of Heat by the Water.

Now, it can be shown (see "Advanced Text-Book," p. 36) that the loss of heat from, or the gain of heat by, any substance is equal to the mass of the substance × its specific heat × its fall or rise in temperature. (See Table below for Specific Heats.)

∴ The *loss* of heat from 1 lb. of platinum $= 1 \times \cdot0324 \times (t^\circ_1 - t^\circ_3)$ and the *gain* of heat by 2 lbs. of water $= 2 \times 1 \times (t_3^\circ - t_2^\circ)$, and these are equal by the above principle.

$$\therefore\ 1 \times \cdot0324 \times (t_1 - t_3^\circ) = 2 \times 1 \times (t_3^\circ - t_2^\circ)$$

$$\therefore\ {}_1^\circ - t_3^\circ = \frac{2\ (t_3^\circ - t_2^\circ)}{\cdot0324} = 62\ (t_3^\circ - t_2^\circ),$$

$$\therefore\ t_1^\circ = 62(t_3^\circ - t^\circ_2) + t_3^\circ.$$

Or, *the temperature of the platinum = 62 times the rise in temperature of the water + the final temperature of the water.*

SPECIFIC HEAT OF SUBSTANCES,

BY REGNAULT AND OTHERS,

From D. K. Clark's "Rules, Tables, and Data," at between 32° and 212° Fah., unless stated.

Water at 39°·1 F.	1·000
,, ,, 212° F.	1·013
Ice at 32°	·504
Steam at 212°	·480
Mercury	·033
Iron, cast	·130
,, wrought	·113
Steel, soft	·116
Copper	·095
Lead	·031
Zinc	·093
Tin	·057
Silver	·057
Platinum, sheet	·0324
,, spongy, at 952° F.	·035
Coal	·240
Coke	·200
Olive oil	·310
Air	·238
Carbonic oxide	·248
Carbonic acid	·217
Hydrogen	3·404
Oxygen	·218
Nitrogen	·244

Lecture V.—Questions.

1. State the general effects of heat upon matter. If you place a round bar of iron in a fire, why does it become longer and larger in diameter?

2. What is the unit of heat adopted in Great Britain? How many units of heat are imparted to a cubic foot of water (62·5 lbs.), on raising it from 60° to 212° F., also to 1 lb. of copper? *Ans.* 9500, and 14·44.

3. What do you mean by the quantity of heat in a body, and how is it measured?

4. How many units of heat are required to raise 1000 lbs. of water from 32° to 212° F.? *Ans.* 180,000.

5. Define and show the difference between the terms "capacity for heat" and "specific heat" of a substance. Suppose a substance was given to you to find its specific heat, how would you conduct the experiment? Give an arithmetical example.

6. If 1 lb. of platinum is plunged into 1 lb. of water at 50° F., and the resultant temperature of the water is 112° F., what was the original temperature of the platinum? *Ans.* 2025° F.

7. If 2 lbs. of copper at 500° F. are plunged into 4 lbs. of water at 60° F., what will be the resulting temperature? *Ans.* 80° F.

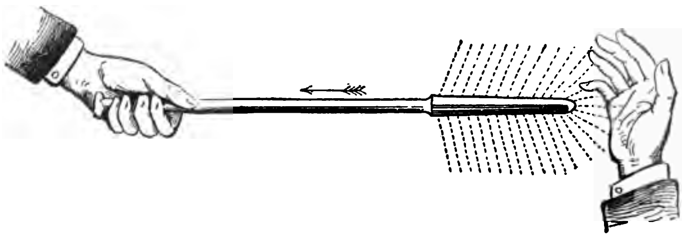
LECTURE VI.

CONTENTS.—Transfer of Heat—Radiation—Conduction—Convection.

Transfer of Heat.—It was explained in the last lecture, that equality of temperature between two bodies exists, when there is no tendency to a transfer of heat from either to the other. We saw also that, when their temperatures differed in the slightest degree, there was a tendency to an equality of temperature, by a transfer of heat from the hotter to the colder, and that this tendency is greater, the greater the difference of temperature between the bodies.

The transfer of heat takes place by three processes, called respectively, *radiation*, *conduction*, and *convection*.

Radiation.—To illustrate the radiation of heat from one body to another, take a common poker, heat it to redness in the fire,



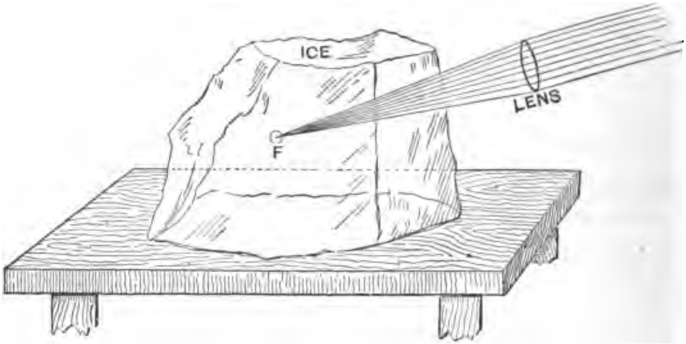
and hold one hand a few inches from the heated end, as shown in the figure.

The hand experiences the sensation called heat, owing to the transfer of the same in straight lines from the hot poker, as it were by radial vibrating rays of heat energy.

Another common, but interesting illustration, is that of making a convex lens of ice, by pressing a heated concave scale-pan of a balance on a block of ice, and holding this lens between the sun and your coat at the proper distance, so as to focus the heat rays on the same. The lens of ice, as well as the air, will be scarcely affected by the heat rays passing through them, while the coat will soon be burned.

An even still more interesting and striking experiment, due

to Professor Tyndall, is that of focussing the heat rays from the sun or a strong electric arc light on the interior of a block of ice. The heat rays pass through the mass of ice without apparently



affecting it, except at the point where they meet; here the ice very soon becomes melted.

The phenomenon of radiation consists, therefore, in the transmission of energy from one body to another by propagation through the intervening medium, in such a way that the progress of the radiation may be traced, after it has left the first body and before it reaches the second, travelling with a certain velocity and leaving the medium behind it in the condition in which it found it. **It is only when the radiation is obstructed that the effects of heat are observed.**

Radiant heat is propagated with a speed practically the same as that of light; for example, after a total eclipse of the sun, the heat rays re-appear simultaneously with those of light, travelling somewhere about 186,000 miles per second. In free space, or in air of uniform density, light moves in straight lines; so does radiant heat, whether from the sun or from a terrestrial source; in fact, radiant heat and light may be regarded as identical and inseparable. Speaking generally, the rate of radiation of heat by the hotter of a pair of bodies, and of its absorption by the colder, are increased by darkness and roughness of the surfaces of the bodies, and diminished by smoothness and polish. The best radiators of heat are likewise the best absorbers of heat, and the poorest reflectors. For example, it will be seen from the following table, that the radiating and absorbing power of soot is a maximum or 100, while its reflecting power is nil—a fact of considerable importance in connection with the generating of steam in boilers. Again, cylinder covers are highly polished; why?—to prevent radiation of heat therefrom.

COMPARATIVE RADIATING, OR ABSORBENT, AND REFLECTING POWERS OF SUBSTANCES.

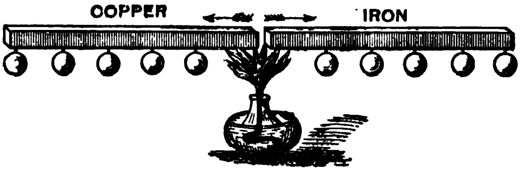
SUBSTANCE.	POWERS.	
	Radiating or Absorbing.	Reflecting.
Lampblack or soot	100	0
Water	100	0
Cast iron, polished	25	75
Wrought ,,	23	77
Steel ,,	17	83
Brass, cast, dead polish	11	89
,, ,, bright	7	93
Copper, hammered or cast	7	93
Silver, polished bright	3	97

Conduction.—*Conduction is the transfer of heat through substances, or from one substance to another when in contact, due to difference of temperature.* It may be conveniently divided into *internal* and *external* conduction, according as the transfer of heat takes place, between the parts of one continuous body, or through the surface in contact of a pair of distinct bodies, although to a large extent external conduction or surface conductivity is an action of the same kind as internal conduction, for the conduction takes place in the surrounding medium. For example, take the heated poker (figure on p. 43), the end held in the left hand becomes gradually heated by the transfer of heat, from molecule to molecule of iron, along the poker in the direction of the arrow, while the hand is heated by the transfer of heat through the surface in contact therewith.

A body which conducts heat quickly, is called a good conductor of heat; if it conducts heat slowly, it is called a bad conductor, or, if *very* slowly, a non-conductor of heat. For example, hold a copper rod in the hand, and place it in the fire in the same way as we did the iron poker, the sensation of heat is felt by the hand much sooner than in the case of the poker, whereas, if we do the same with a piece of wood, of the same length and cross-section as the poker, or the bar of copper, it will be entirely burnt away at the end placed in the fire, before any appreciable heat is conducted to the hand.

A common class experiment to illustrate the different conducting powers of bodies is that shown by the following figure, where small balls are attached by wax at regular intervals to two rods or bars, *e.g.*, copper and iron, and heat applied to their inner ends simultaneously, and equally, as shown.

The balls attached to the copper bar fall off, by the melting of the wax, much sooner than those hanging from the iron



one, thus proving conclusively that copper is a better conductor of heat than iron, although their capacities for heat are about the same.

Thermal conductivity must be measured (other things being equal) by the quantity of heat which passes; therefore the rate at which conduction (whether internal or external) goes on, is proportional to the cross area of the section, or the surface through which it takes place. It may be expressed numerically in so many units of heat per square foot per minute, or per hour. For example, engineers speak of the evaporating power of a boiler, as so many pounds of water raised into steam at a certain pressure per square foot of grate surface per hour, or plus per square foot of the additional heating surfaces, although in reality it depends on many things besides the mere conduction of the plates.

To compare plates of different materials, we must take them all of the same thickness and superficial area, and subject them all on the one side to a certain temperature, and on the other side to the same number of degrees more or less.

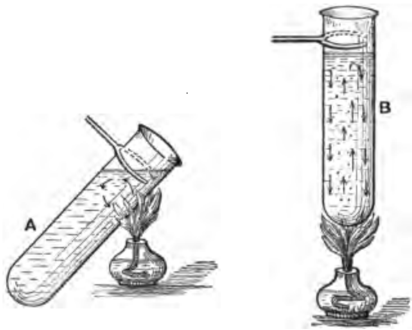
It is important that the engineer should appreciate the relative conducting capabilities of the different metals that he has to deal with. For instance, the fire-box of a locomotive is made of copper in preference to iron, partly on account of its greater conductivity and partly on account of its withstanding the destructive action of the fire better. Again, the outsides of boilers and of cylinders are carefully lagged with some badly conducting substances, such as hair or felt, and wood, so that as little heat as possible may escape therefrom. The following table gives roughly the relative conductivities of a few of the more common metals :—

Substance.	Relative Conductivity.	
Copper	100	
Brass	30	and upwards, according to percentage of copper in it
Zinc	30	
Iron	16	
German Silver	10	
Water	0·2	

Convection.—When the application of heat to a fluid causes it to expand or to contract, it is thereby rendered rarer or denser than the neighbouring parts of the fluid; and if the fluid is at the same time acted on by gravity, it tends to form an upward or downward current of the heated fluid; this is accompanied with a current from the more remote parts of the fluid in the opposite direction. This action is rendered very apparent by the following simple experiment:—

Take a flask partially filled with water, mix a few grains of bran with it, and apply a lighted spirit-lamp to the bottom of the flask. In a few minutes the water will be seen to circulate in the direction shown by the arrows in the figure. The water nearest the flame is rendered lighter, and, therefore, rises upwards, while the denser water falls under the action of gravity, to be in turn heated and raised. The actual transfer of heat throughout the water takes place by conduction, but the diffusion is much assisted by the motion of the fluid, or convection currents, as they are termed.

The following experiment is also very instructive:—Take a test tube filled with water (left hand, Fig. A), and apply a spirit-



lamp near the surface of the water. You may hold it there for ten minutes or more, and the water at the bottom of the tube is scarcely perceptibly warmer than at first. Now apply the lamp to the bottom of the tube (right hand, Fig. B); in a few minutes the water begins to boil. Why this difference? The convection

currents set up have assisted the naturally bad conducting power of the water by bringing, in turn, every portion of it into close proximity with the source of heat.

It is for the reasons just mentioned, that the fire-place in a boiler is placed near the bottom instead of near the surface of the water, and it is of great moment not only to give a free and easy path for convection currents in boilers, but to stimulate them by such appliances as hydro-kineters. The better the circulation of the water in a boiler, the more rapidly will it be heated and the steam generated. In many boilers (such as those used on board steamers) the internal construction is so mixed up with tubes and stays, that the water has great difficulty in passing from out-of-the-way corners to the more highly heated parts over the flues; and, if circulation is not assisted, the convection currents "short circuit," as it were (to use an electrical term), and thus leave the more remote portions in comparative chill. For a similar purpose, large boiler flues are provided with "baffling plates," to compel the hot gases to take a circuitous course, in order that eddies may be formed, and for the further object of promoting a better mixture of air with the inflammable gases.

The art of promoting a good draught in a furnace, or of properly ventilating a building or a ship, depends upon inducing and guiding the convection currents in the proper direction. This subject is, therefore, of considerable importance to engineers.

LECTURE VI.—QUESTIONS.

1. Name the different ways by which heat is transferred from one part of a body to another part of the same body, and also from one body to another not in contact with it.

2. Explain, and illustrate by an example not mentioned in this lecture, how radiation takes place. Why are the covers of steam-engine cylinders polished or electro-plated?

3. Explain, and illustrate by an example of your own, how conduction of heat takes place in bodies. Name four of the best conductors in their order of conductivity. Name also a few of the worst conductors.

4. What is meant by "convection currents"? How does convection assist the engineer in raising steam in a boiler? Illustrate your answers.

5. Describe an experiment by which you would show that water is an extremely bad conductor of heat. For what reason should heat be applied from below when it is required to heat a large mass of water rapidly?

LECTURE VII.

CONTENTS.—Nature of Heat—Heat is not a Substance—Rumford, Davy, and Joule's Experiments—Conversion of Work into Heat—Joule's Mechanical Equivalent of Heat—First Law of Thermo-dynamics.

UNTIL the end of last century, two rival theories had been entertained regarding the nature of heat—one, that heat consisted of a subtle elastic fluid, termed caloric, penetrating through the pores or interstices of matter, like water in a sponge; the other, that it was an internal commotion among the particles or molecules of matter.

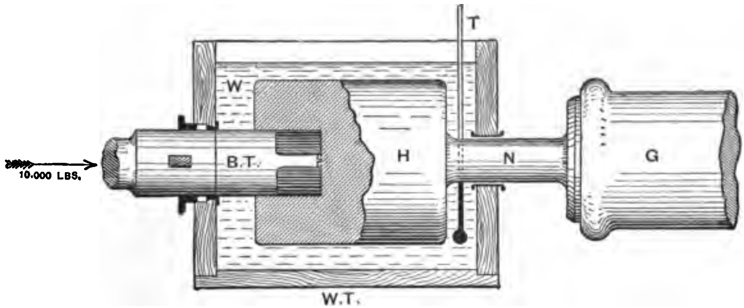
The former of these theories, or hypotheses, that heat is matter, called the "materialistic doctrine of heat," taught by Professor Black of Glasgow University and others, was most conclusively overthrown by the celebrated experiments of Count Rumford and Davy. It is very remarkable, however, that fifty years elapsed before scientific men generally became converted to the conclusions to be drawn from them. It was not until Joule, during the period extending from 1840 to 1849, had supplied several fresh proofs that heat is not a material substance, but one form of energy, which may be applied to or taken from bodies in various ways, and that the amount of energy, in whatever form applied or removed, may be estimated in mechanical units of work or foot-pounds, that what is now known as the *Kinetic theory of heat*, became generally accepted, and the science of thermo-dynamics placed on a firm basis.

Count Rumford's experiments on the production of heat by friction, were carried out in the following manner, and communicated to the Royal Society in 1798:—

In casting guns it was usual to leave a projecting cylindrical "head" of metal at the muzzle, so as to insure sound metal in the gun. The guns were cast in a vertical position with the muzzle end upwards, very much in the same way as large water or gas pipes are now made, the effect of adding the "head" to the casting being to add pressure to the fluid metal in the lower parts, thus expelling air and gases towards the surface, and into the "head," which was cut off before boring out the gun.

Rumford obtained a casting for a six-pounder brass gun from

the military arsenal at Munich, and surrounded the "head," H, by a wooden trough, W T, containing about 18 lbs. of water, W, at 60° Fah. The machinery which rotated the gun, G, was driven by two powerful horses. A blunt boring tool, B T, which was made of steel, 3·5 inches diameter, was forced against the head, H.



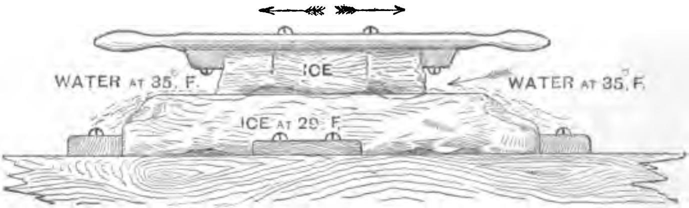
COUNT RUMFORD'S EXPERIMENT.

G for Gun.
N „ Neck.
H „ Head.
B T „ Boring tool.
W T for Wooden trough.
W „ Water.
T „ Thermometer.

This boring tool was held firmly in a rest, and pressed forward by means of a screw with an estimated pressure of 10,000 lbs. The result of this experiment was, that the heat generated by the friction between the blunt boring tool and the metal of the head, was partly conducted through the neck connecting the head with the gun, and partly absorbed by the water in the trough, so that the temperature of the water rose at the end of an hour to 107° F., in an hour and a half to 142° F., in two hours to 178° F., and, finally, at the end of two and a half hours the water boiled. Count Rumford said—"It would be difficult to describe the surprise and astonishment expressed in the countenances of the bystanders on seeing so large a quantity of water heated, and actually made to boil without any fire!" He adds—"By meditating on the results of these experiments, we are naturally brought to that great question which has so often been the subject of speculation, namely—What is heat? Is there any such thing as an igneous fluid? Is there anything that, with propriety, can be called caloric?" And, further—"It is hardly necessary to add that anything which an insulated body or system of bodies can continue to furnish without limitation, cannot possibly be a material substance; and it appears to me to be extremely difficult, if not impossible, to form any distinct idea of anything capable of

being excited, and communicated in the manner heat was excited, and communicated in these experiments, except it be motion."

Davy's experiment on the melting of ice by friction, announced by him in 1799, in his first published work, entitled—*An Essay on Heat, Light, and Combinations of Light*, was regarded at the time as a complete refutation of the materialistic doctrine of heat.



Sir Humphry Davy's Experiment.

In an atmosphere at a temperature of 29° F., he rubbed together two small slabs of ice with the result (as shown in the fig.) that the ice was melted at the surfaces of contact, producing water at a temperature of 35° F. Now, as we saw in Lecture V., a mass of water contains an absolute quantity of heat greater than an equal mass of ice, and it is, therefore, impossible to account for the presence of the increased temperature on the assumption that heat is a material substance. Davy said—"The immediate cause of the phenomenon of heat is motion, and the laws of its communication are precisely the same as the communication of the laws of motion."

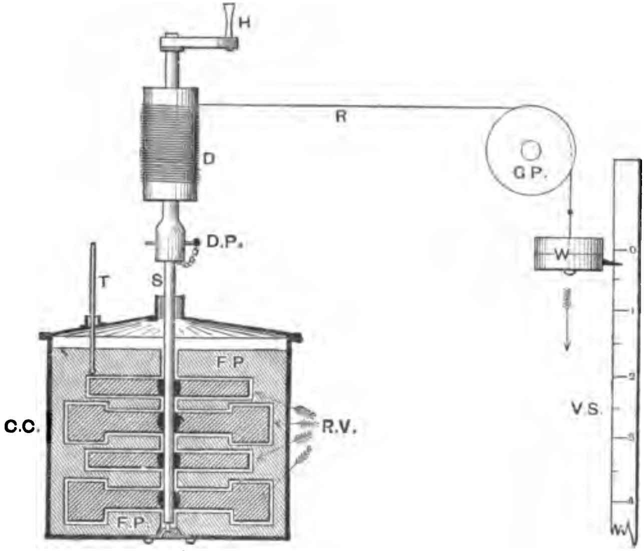
Maxwell, in his *Theory of Heat*, p. 306, says—"The molecules of all bodies are in a state of continual agitation. The hotter the body is, the more violently are its molecules agitated."

Joule's experiments, carried out between 1840 and 1849, recalled the attention of scientists to Rumford and Davy's doctrine regarding the nature of heat, and gave us the means of estimating with exactness the quantity of work required to generate a certain quantity of heat.

Joule's favourite experiment was the conversion of work into heat by the stirring of water. He arranged his apparatus in a manner similar to that shown in the following figure.

A known weight, W, was allowed to fall through a known height, and in doing so to revolve vanes or paddles, R V, inside a copper cylinder, C C, containing a known weight of water; thus churning the water against the fixed plates or stationary screens, F P. The effect of this churning was to raise the temperature of the water, by imparting to it a certain quantity of heat, depending on the product of the weight into the space

through which it fell, or the foot-pounds of work expended. We need not enter into the many details of Dr. Joule's carefully con-



JOULE'S WATER-STIRRING EXPERIMENT.

VS	for Vertical scale in feet.	C C	for Copper cylinder.
W	,, Weight.	T	,, Thermometer.
R	,, Rope or twine.	R V	,, Revolving vanes or paddles (8 sets).
G P	,, Guide pulley.	F P	,, Fixed plates (4 sets).
D	,, Drum.	D P	,, Disconnecting pin.
H	,, Handle.		
S	,, Spindle.		

ducted experiments, whereby he eliminated from his results the effect of friction in the guide pulley, G P, as well as the effects of radiation and conduction of heat to or from the apparatus during the time of the experiment, &c. It will suffice to give his final result and an example.

The British Association in 1870 requested Joule to re-investigate the subject, for the purpose of giving greater accuracy to the determinations by his fluid friction method, with the final result of proving that 772·43 *foot-pounds* (*at the latitude of Manchester*) *are equal to the quantity of heat required to warm from* 60° *to* 61° *Fah. a pound of water weighed in vacuum.* This has been termed "Joule's Mechanical Equivalent of Heat," or, shortly, "Joule's Equivalent," and is denoted in formulæ by the letter J. In round numbers we say, 1 *British thermal unit* = 772 *ft.-lbs.*

For instance, suppose that, with Joule's apparatus we had used a weight of 77·2 lbs., and had allowed it to fall through a height of 10 feet. In doing so, let the mechanical work (772 ft.-lbs.) be converted into heat by churning 1 lb. of water at 60° F. We should then find (if all extraneous losses were avoided) that the water had risen in temperature to 61° F., when the weight passed the 10th foot. Again, if we took 1 lb. of water at 60° F., and raised its temperature 1° F., by any method whatever, the quantity of heat imparted to it (viz., 1 thermal unit), if converted into mechanical energy by a perfect heat engine, would perform 772 ft.-lbs. of work, or raise 772 lbs. 1 foot.

First Law of Thermo-dynamics.—*Heat and work are mutually convertible, and Joule's equivalent is the rate of exchange.*

The importance of this mutual relation between *heat* and *work* cannot be too strongly impressed on the student at the very outset of his studying steam and the steam engine. In this lecture it has been shown that the expenditure of so many *units of work* produces, under the circumstances noted, an exact and unvarying equivalent of so many *units of heat;* and we shall see in future lectures how the expenditure of so many *units of heat* produces an equivalent in *units of work.*

A familiar illustration of the foregoing principle of the mutual convertibility of heat and work is that of the Locomotive Engine. In the furnace we have the production of heat by the combustion of coal. A proportion of this heat is imparted to the water in the boiler, thus raising steam. The steam on being admitted to the cylinders parts with a portion of its heat in the act of doing the work of propelling the pistons, and thus moving the train. Again, when the train is nearing a station the steam is shut off, and the brakes applied. Then the stored work is converted into heat, which may be observed by sparks issuing at the brakes, and by feeling the increased temperature of the brakes, wheels, and rails.

EXAMPLE I.—Suppose a locomotive burns 6 lbs. of coal per horse-power per hour, and that every pound of coal burned in the furnace gives up to the water in the boiler 10,000 British units of heat, we have—

$$6 \text{ lbs.} \times 10{,}000\, u = 60{,}000 \text{ units of heat per H.P. per hour.}$$

But— $1 \text{ H.P.} = 33{,}000 \text{ ft.-lbs. per minute,}$
$\qquad = 33{,}000 \times 60' = 1;980{,}000 \text{ ft.-lbs. per hour.}$

And— $772 \text{ ft.-lbs.} = 1 \text{ unit of heat.}$

$$\therefore \quad \frac{1;980{,}000}{772} = 2564{\cdot}7 \text{ units of heat converted into work every hour.}$$

Consequently— $60{,}000\, u : 2564{\cdot}7\, u :: 100 : x = 4{\cdot}27,$

Or the locomotive only converts 4·27 per cent. of the total heat generated in the furnace into its equivalent of work in the cylinder.

EXAMPLE II.—Suppose that the energy of the train when the brakes are put on is equal to 16;500,000 ft.-lbs.

Then, $16;500{,}000 \div 772 = 21{,}373$ units of heat, or an amount of heat is generated at the brakes wheels, and rails, &c., which would raise 213·73 lbs. of water 100° F.

Note.—We thus see from these two examples that the transformation from work into heat is more easy and complete than from heat into work.

EXAMPLE III.—An engine develops 10 H.P.; how many units of heat does it convert into useful work per minute and per second?

$$10 \text{ H.P.} = 10 \times 33{,}000 = 330{,}000 \text{ ft.-lbs. per minute}$$
$$= \frac{330{,}000}{60} = 5{,}500 \text{ ft.-lbs. per second.}$$

But 1 unit of heat = 772 ft.-lbs.

$\therefore$ 772 ft.-lbs. : 330,000 ft.-lbs :: 1 heat unit : x heat units.

$$x = \frac{330{,}000}{772} = 427 \text{ units of heat per minute.}$$

And similarly—

$$y = \frac{5500}{772} = 7\cdot1 \quad ,, \quad ,, \quad \text{per second.}$$

Or,

$$y = \frac{427}{60} = 7\cdot1 \quad ,, \quad ,, \quad ,,$$

LECTURE VII.—QUESTIONS.

1. Give free-hand sketches with index of parts, and a description in *your own* words of Rumford's, Davy's, and Joule's experiments.

2. State in your own words what you consider heat to be, and give Joule's mechanical equivalent for one British thermal unit.

3. How has the work done in raising the temperature of a pound of water through one degree been ascertained? A pound of coal gives out during combustion 12,000 units of heat; how much work in foot-pounds could be done per pound of coal burned, if there were no waste? *Ans.* 9;264,000 ft.-lbs.

4. It is estimated that every pound of average steaming coal burned in the furnace of a boiler gives out 13,000 units of heat. It is found that a good compound engine and boiler require 2 lbs. of coal per hour per indicated horse-power. What is the efficiency of the combined boiler and engine? *Ans.* 9·8 per cent.

5. Define a unit of heat. A steam engine indicates 25 H.P.; how many units of heat does it convert into useful work per minute? (S. and A. Exam., 1888.) *Ans.* 1068·8.

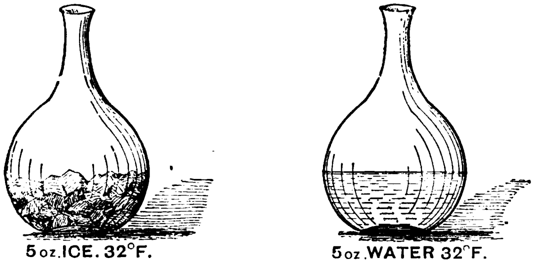
6. Using Fahrenheit's thermometer, define the British standard unit of heat. To what amount of energy, expressed in British units of work, is this heat unit equivalent? How many units of work must be converted into heat in order to raise the temperature of 3 lbs. of water from 50° F. to 120° F.? *Ans.* 772 ft.-lbs.; 162,120 ft.-lbs. (S. and A. Exam., 1894.)

LECTURE VIII.

CONTENTS.—Sensible and Latent Heats of Water and Steam—Worked Examples—Explanation of Sensible and Latent Heats by the Kinetic Theory of Heat.

Sensible and Latent Heats of Water and Steam.—Hitherto we have dealt with heat when imparted to or abstracted from bodies as indicated by a rise or fall of temperature in the body. It has been customary to call this condition *sensible heat;* but there are exceptional cases in which temperature does not vary in a mass of matter when heat is communicated to it from, or taken from it to, external matter. For instance, when the body is ice at the melting point, heat communicated to it does not raise its temperature above 32° F., or, if the body be water at the boiling point in the open air, heat slowly communicated to it, in however great a quantity, does not raise its temperature above 212° F., at the normal pressure of the atmosphere. This heat is termed *latent heat.*

A short account of Professor Black's well-known experiments, carried out about 1762, will serve to illustrate the difference between what is termed the "sensible" and the "latent" heat of a substance.



BLACK'S EXPERIMENT ON LATENT HEAT OF WATER.

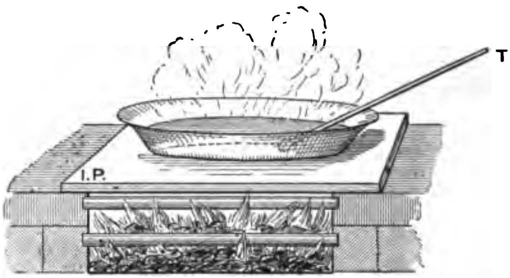
Black procured two glass flasks, in one of which he placed 5 ozs. of ice at 32° F.,* and in the other 5 ozs. of water at the same

* The ice was beginning to melt, and his estimate of the temperature at the surface was 33° F.

temperature. He suspended them within a short distance of each other in a room which remained at a uniform temperature of about 47° F. He observed that in *one* half-hour the water increased in temperature by 7° F., but that it took *twenty* half-hours for the whole of the ice in the other flask just to become melted, and he reasoned thus—that from the time required the amount of heat which had entered the ice must have been *twenty* times as much as that which entered the water. He, therefore, computed that the *latent heat* of water must be 7×20 (half-hours) $= 140$.

Another experiment of Black's was that of placing a lump of ice in an equal weight of water at 176° F., with the result that when the whole of the ice had melted, the temperature was no greater than that of water just ready to freeze. Therefore, assuming the final temperature of the mixture to have been 33° F., we have $176 - 33 = 143$, as the amount of heat required to melt the ice, or *the latent heat of water*.

In this estimate he was very near the truth; for, even at the present day the mean result of some of the best experimenters appears to be, that 143 British thermal units of heat are absorbed, or become latent, in the conversion of 1 lb. of ice into water at the same temperature; and, consequently, 143 B.T.U., are given out or let free in the conversion of 1 lb. of water at 32° F., into ice at the same temperature.*



BLACK'S EXPERIMENT ON THE LATENT HEAT OF STEAM.

Black's third experiment consisted in placing a flat tin dish on a hot plate over a fire; into this plate he put a small quantity of water at 50° F., and observed that after 4 minutes the water began to boil, and in 20 minutes more it had all evaporated. Now, since the water increased by $(212° - 50°) = 162°$ in 4 minutes, he

* The latent heat of water by the Centigrade scale is 79·4; for, $\frac{143 \times 5}{9} =$ 79·4, say 79 units of heat required to convert 1 lb. of ice at 0° C. into 1 lb. of water at the same temperature.

reasoned that it must have been receiving heat at the same rate throughout the experiment, or that in 20 minutes it had absorbed five times as much as in the first 4 minutes without any apparent rise in temperature as indicated by the thermometer, or, $5 \times 162 = 810$—Black's estimate of the latent heat of steam.

In this last estimate Black was incorrect, as might be expected, from the rough nature of his experiment. It has since been found that the *latent heat of steam* at atmospheric pressure is 966·6. In other words, it requires 966·6 British thermal units of heat to convert 1 lb. of water at 212° F., into steam at the same temperature, or 1 lb. of steam at 212° F., gives out 966·6 B.T.U., in being condensed into water at the same temperature.*

The following definition of sensible and latent heat will now be quite clear:—

"Heat given to a substance, and warming it, is said to be *sensible* in the substance. Heat given to a substance, and *not* warming it, is said to become *latent*" (*Sir Wm. Thomson*).

Latent heat is the quantity of heat which must be communicated to (unit mass of †) a body in a given state, in order to convert it into another state without changing its temperature (*Maxwell*).

In order to impress on junior students the foregoing statements with regard to the latent heats of water and steam, we now give a few examples worked out in detail. The student should carefully study them, and then work them out for himself; or, these examples, as well as several of the questions at the end of this lecture, may with advantage be worked out on the blackboard by the teacher.

EXAMPLE I.—How many pounds of ice at 32° F. will be converted into water at 40° F. by mixing it with 6 lbs. of water at 160° F.?

6 lbs. of water *gives* up $6(160^\circ - 40^\circ) = 720$ units.
1 lb. of ice *takes* up $143 + (40 - 32) = 151$ „
$\therefore 720 \div 151 = 4·768$ lbs.

EXAMPLE II.—Into 1 cwt. of water at 45° F. are poured 20 lbs. of water at 160° F., and then 4 lbs. of ice at 32° F. are added. What is the final temperature when the ice has just melted?

* The Latent Heat of Steam by the Centigrade scale, is, therefore $\frac{966·6 \times 5}{9} = 537$; or, 537 times the quantity of heat absorbed in raising 1 lb. of water by 1° C.

† I have added the words (unit mass of) to Maxwell's definition, because it appears deficient without them. When we speak of 143 as the latent heat of water, and 966 as the latent heat of steam, it is understood that 143 and 966 units of heat are required respectively for every 1 lb. (or unit of mass) to change the state from solid to liquid, and from liquid to gaseous.—*A. J.*

Water	112 $(45^\circ - 32^\circ)$	=	$+1456$	units of heat from 32° F.
Water	20 $(160^\circ - 32^\circ)$	=	$+2560$	" "
Ice	4 × 143	=	-572	to convert 4 lbs. ice into water
Total	136 lbs. mixture	=	3444	units left.

$\therefore 3444 \div 136 = 25{\cdot}32$ above 32° or $57^\circ{\cdot}32$ F.

EXAMPLE III.—If the heat which just melts 8 lbs. of ice at 32° F. were applied to 30 lbs. water at 60° F., to what temperature would the water rise?

$8 \times 143 = 1144$ units of heat required to melt the ice.

Now, 30 lbs. of water raised 1° F. = 30 units of heat,

$\therefore 1144 \div 30 = 38^\circ{\cdot}13$ F. of rise from 60° F. or $98^\circ{\cdot}13$ F.

EXAMPLE IV.—There are mixed together 200 lbs. of water at 100° F., 3 lbs. steam at atmospheric pressure, and 15 lbs. of ice at 32° F. What is the resulting temperature when all the ice is just melted.

The	200 lbs.	water	have	+ 13,600 *u*,	more than	water at	32° F.
"	3 "	steam	"	+ 3,438	"	"	"
"	15 "	ice	"	− 2,145	less	"	"
∴	218 "	mixture	"	14,893	more	"	"

And $14{,}893 \div 218 = 68^\circ{\cdot}3$ F. above $32 = 100^\circ{\cdot}3$ F.

EXAMPLE V.—If one pound of Newcastle coal develops 12,000 units of heat by its complete combustion, how much water at 60° F. should be converted into steam at 212° F. by the consumption of 1 cwt. of such fuel, assuming that there is no loss of heat during the operation? (S. & A. Exam., 1887.)

Every pound of water in being raised from 60° F. to 212° F. absorbs—

1 lb. $(212^\circ - 60^\circ) = 152$ units of heat.

Every pound of water raised to 212° F., in being converted into steam at the same temperature (212° F.), absorbs—

966 units of heat.

$\therefore$ Every pound of water at 60° F., in being converted into steam at 212° F., absorbs—

152 units + 966 units = 1118 units of heat.

From the question we are informed that every pound of coal develops—

12,000 units of heat.

$\therefore$ 1 cwt. of coal develops—

112 lbs. × 12,000 units = 1,344,000 units of heat.

Consequently, as:—

1118 units : 1,344,000 units :: 1 lb. water : x lbs. water.

$$\therefore x = \frac{1{,}344{,}000 \times 1}{1118} = 1202{\cdot}1 \text{ lbs. of water.}$$

Now since 1 gallon = 10 lbs.—

$$\frac{1202{\cdot}1}{10} = 120{\cdot}21 \text{ gallons,}$$

And since 1 cubic foot of water = 62·5 lbs.—

$$\frac{1202{\cdot}1}{62{\cdot}5} = 19 \text{ cubic feet of water.}$$

Explanation of Sensible and Latent Heats by the Kinetic Theory of Heat.—According to the kinetic theory, heat is a rapid vibratory motion of the ultimate particles of matter, and temperature is the outward manifestation of this motion. An increase or a decrease in the temperature of a body means an increase or a decrease of molecular kinetic energy. Hence, by "sensible" heat is meant that heat which is effective in changing the molecular kinetic energy of the body. The sensible heat given to 1 lb. of water between the temperatures 32° F. and 212° F., is 180 B. T. U., and the whole of this heat is employed in giving a more rapid vibratory motion to the molecules of the water.* The amount of work done in increasing the kinetic energy of the molecules of the water during this change of temperature may be mentally pictured in this way. The sensible heat is equivalent to $180 \times 772 = 138{,}960$ ft.-lbs. of mechanical work, and corresponds to the work done in raising a weight of rather more than 62 tons through a vertical height of 1 foot; or, it is equivalent to the work done in projecting a 5 lb. shot from a gun with a velocity of 1336 ft. per second! The whole of this work, be it remembered, has been done within the mass of 1 lb. of water between the freezing and boiling points. If, then, by any contrivance we convert the whole of the heat given out during the cooling of 1 lb. of water from its boiling to its freezing point, we should be able to do mechanical work to the extent of 138,960 ft.-lbs.

We have shown, that during the conversion of a solid into a liquid, or a liquid into a gas, an amount of heat disappears without in any way affecting a thermometer placed in the mixture; until, the change of state of the whole mass has been completed. Thus, in converting 1 lb. of ice at 32° F. into water, 143 B. T. U. disappear before a change of temperature takes place. In the same way, 966·6 B. T. U. disappear during the conversion of 1 lb. of water at 212° F. into steam at the same temperature. The question may then be asked, what becomes of this heat? Evidently no part of it is employed in increasing the kinetic energy of the molecules of the body, otherwise this would be indicated by an increase of temperature. The older physicists, believing that heat was a substance—a highly elastic, imponderable and subtle fluid, called *caloric*—accounted for the above phenomenon by saying that this "caloric" became *latent* or hidden in some out-of-the-way holes or pores of the body. But we now know that heat is not a substance, and we cannot conceive of any such

* We shall see in Lecture X*a*. that rather less than 180 B. T. U. are employed in increasing the molecular kinetic energy; but the difference is so small that we may safely neglect it.

cavities or pores in matter wherein this "caloric" could possibly conceal itself in the manner suggested. Further, this disappearance of heat never occurs except when there is a change of state of the body. To clearly understand what actually takes place we require to give a brief explanation of the fundamental differences of the three states of matter as presented to our senses. According to the theory of the *molecular constitution of matter*, the distinctive character of a solid is the fixedness of the molecules relatively to each other. The molecules have a rapid tremulous motion about their mean positions, but are otherwise so firmly bound to their neighbours that work has to be done against the molecular attractions before they can be given greater freedom of movement or separated from each other. Hence, considerable effort is required to separate one portion of a solid from the remainder of the mass. Whenever the molecular attractions are sufficiently overcome, that the molecules glide freely over each other and move about throughout the whole mass, we have all the characteristics of a liquid. The greater the mobility of the molecules the more perfect is the liquid. Hence, the difference between a solid and a liquid is the ease with which the parts of the latter can be separated from each other, and the readiness with which the whole assumes the form of the containing vessel. With gases, on the other hand, the mobility of the molecules is very much greater than in the case of liquids. Here the molecular forces are repulsive, and these cause the molecules to separate from each other as far as the sides of the containing vessel will permit. Thus, a portion of gas, however small, when allowed to enter a vessel, however large, soon diffuses itself equally throughout the whole vessel, and this is true whether there are other gases or not in the vessel along with it.

We are now in a position to understand what becomes of the so-called *latent* heat. In converting a solid into a liquid, or a liquid into a gas, work has to be done in effecting certain molecular actions, as in overcoming the molecular attractions characteristic of solid substances, or bringing into play those molecular repulsions characteristic of the gaseous state. Hence, during those transient states of matter, the so-called latent heat disappears as heat, but reappears as the result of molecular mechanical work.

As before, we may give a mental picture of the vast amount of work done within the mass of 1 lb. of water during those physical changes.

In converting 1 lb. of ice at 32° F. into water at the same temperature, 143 B. T. U. (or, $143 \times 772 = 110{,}396$ ft. lbs. of work) have been expended against the molecular attractions.

This corresponds to the work done in raising a weight of about 49½ tons through a vertical height of 1 foot; or the work done in projecting a 4 lb. shot from a gun with a velocity of about 1330 feet per second!

In converting 1 lb. of water at 212° F. into steam at the same temperature, 966·6 B. T. U. (or, $966·6 \times 772 = 746{,}215$ ft. lbs. of work) are expended in bringing about this physical change. This corresponds to the work done in raising a weight of rather more than 333 tons through a vertical height of 1 foot; or the work done in projecting an 18 lb. shot from a gun with a velocity of more than 1600 feet per second!

Conversely, when 1 lb. of steam at atmospheric pressure (212° F.) is condensed into water at the same temperature, the work done by the colliding or "clashing" of the molecules corresponds to 746,215 ft. lbs. or 966·6 B. T. U.*

If, then, an engine could convert the whole of the heat given out during the reduction of steam at 212° F. into water at the same temperature, mechanical work to the extent of 746,215 ft. lbs. would be done per. lb. of steam condensed. We shall afterwards see that only a very small fraction of this work can be made use of in practice.

* We shall see in Lecture X*a*. that the whole of the 966·6 B. T. U. are not employed in molecular work; for about 73 B. T. U. go to perform work *external* to the substance.

Lecture VIII.—Questions.

1. What is the distinction between sensible and latent heat? Define a "thermal unit."

2. Describe an experiment by which you could show that heat becomes latent when water is converted into steam.

3. When you speak of the "latent heat of steam," what property of steam do you refer to? State the numerical value of the latent heat of steam at 212° F. A pound of water at 212° F. is passed into 20 lbs. of water at 70° F.; what is the temperature of the water at the close of the operation? *Ans.* 76°·7.

4. What is meant by saying that the latent heat of steam is 966·6°? Point out the sources of error in Black's experiment when he tried to find the latent heat of steam.

5. How much ice at 0° C. will be converted into water at 5° C. by mixing it with 10 lbs. of water at 80° C.? *Ans.* About 9 lbs.

6. The latent heats of 1 lb. of water and 1 lb. of steam are respectively 143 and 966·6, according to the Fah. scale; work out in full by proportion what they are according to the Cent. scale. *Ans.* 79·4 and 537.

7. How many British units of heat are required to raise 1 cubic foot of water (62·5 lbs.) from 15° C. to 100° C.? *Ans.* 9562·5.

8. What is the resulting temperature on mixing 20 cubic feet of water at 212° F. with 100 cubic feet at 10° C.? *Ans.* 77° F.

9. How many units of heat would be absorbed in raising 18 lbs. of steam of atmospheric pressure from water at 65° F.? *Ans.* 20,034.

10. How much water at 53° F. could just be brought to the boiling-point by the latent heat given up by 2 lbs. of steam at atmospheric pressure being condensed? *Ans.* $(966 \times 2) \div 159 = 12 \cdot 16$ lbs.

11. Define the terms *latent heat, foot-pound, thermal unit.* Write down the number which expresses the latent heat of steam at 212° F., and explain how that number is arrived at. (S. and A. Exam. 1890.)

12. When does heat become latent? What do you understand by the expression *latent heat of steam?* What unit is adopted for measuring and comparing quantities of heat? Write down the number expressing the latent heat of steam at 212° F. (S. and A. Exam. 1891.)

13. What is the thermal unit employed in this country? State its measure in foot-pounds. How many thermal units are expended in converting one pound of water at 60° F. into one pound of steam at 212° F.? (S. and A. Exam. 1892.) *Ans.* 1118·6.

14. Distinguish between the sensible and latent heat of steam. How many thermal units must be added to 1 lb. of water at 32° F. to raise it to 212° F. and evaporate it into steam? How many of these units go to sensible and how many to latent heat? (S. and A. Exam. 1893.) *Ans.* 1146·6 B. T. U.; 180 B. T. U.; 966·6 B. T. U.

15. Write a brief essay explaining what you consider "sensible" and "latent" heat to be; and illustrate the same by means of one or two examples.

LECTURE IX.

CONTENTS.—Total Heat of Evaporation—Graphic diagram representing the Changes from Ice into Water and Water into Steam—Quantity of Water required for Condensation of Steam, with Examples for a Jet Condenser.

Total Heat of Evaporation.—The total heat of evaporation is the sum of the sensible and the latent heats of evaporation, and is approximately a constant quantity for pressures near the atmospheric pressure.

The heat required to elevate the temperature of 1 lb. of water from the freezing point, 32° F., to the temperature of evaporation, is called the *sensible heat*,* and the additional heat required to evaporate it is termed the *latent heat* (see Lecture VIII.).

The total heat of evaporation for water is, therefore, the quantity of heat in thermal units necessary to raise 1 lb. of water from the freezing point, 32° F., to the particular temperature at which it is being evaporated, and to evaporate it at that temperature.

Let H stand for the Total heat of evaporation in B.T.U.
S " " Sensible heat " "
L " " Latent heat " "

Then, $H = S + L$.

Now, since we have defined a unit of heat to be the quantity of heat necessary to raise 1 lb. of water by 1° Fah., the amount of heat imparted to 1 lb. of water, in raising its temperature from 32° F. to 212° F., must be $(212 - 32) = 180$ such units; or the *sensible heat* of steam at 212° F., is said to be 180 units per lb., or **180**. Again, we saw that the *latent* heat of steam at 212° F. was in round numbers 966 units per lb., or **966**.

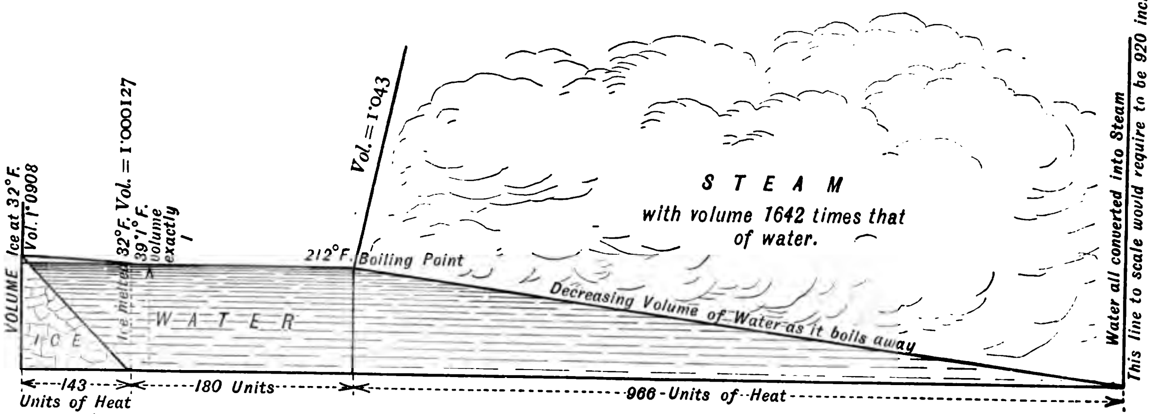
Consequently, the *total heat* of steam at that temperature must be—

$$\begin{aligned} H &= S + L \\ &= 180 + 966 \\ &= 1146 \text{ Units of Heat.} \end{aligned}$$

The following figure will clearly explain this, and should be carefully studied.

* The reason for starting from the freezing point of water, and not from zero Fah., is that we thus avoid the introduction of the latent heat of water.

GRAPHICAL REPRESENTATION OF THE CHANGES FROM ICE INTO WATER, AND WATER INTO STEAM AT ATMOSPHERIC PRESSURE, DUE TO THE ABSORPTION OF HEAT, WITH THE CORRESPONDING TEMPERATURES AND VOLUMES.



Explanation of Diagram.—Distances measured horizontally from the left indicate units of heat absorbed, while distances measured vertically indicate volumes. We commence with ice occupying a volume of 1·0908. The application of heat to the ice (which is supposed to be at 32° F.) immediately begins to melt it, and when 143 units per lb. have been absorbed, the whole of the ice is melted, and we have water occupying a volume 1·000127. The further application of heat causes the volume of this water first to decrease to 1 (at a temperature of 39°·1) and then again to increase to 1·043 at boiling point. After this, the application of each unit of heat causes $\frac{1}{966}$ part of the water to pass away as steam, and when 966 units per lb. have been absorbed the whole of the water has passed into steam, which now occupies a volume 1642 times that of the water from which it was produced.

If steam is generated at a higher temperature than 212° F., the sensible heat increases, and the latent heat decreases.

The following formula, deduced from Regnault's experiments, gives approximately the *latent heat* of steam produced at other temperatures Fah.:—

$$L = 966 - 0{\cdot}7\ (t^\circ - 212^\circ),$$

where L, is the latent heat, and t°, the temperature of evaporation on Fahrenheit scale.

Consequently, the total heat of evaporation, at any temperature, t, must be—

$$\begin{aligned} H &= S + L \\ &= (t^\circ - 32^\circ) + 966 - 0{\cdot}7\ (t^\circ - 212^\circ) \\ &= 1082{\cdot}4 + 0{\cdot}3\ t^\circ. \end{aligned}$$

For example.—Let us find from this equation the total heat of steam at 212° F. Then $t = 212^\circ$ and $\cdot 3 \times 212 = 63{\cdot}6$, which, added to $1082{\cdot}4 = 1146$, the number we got before.

The following table gives approximately the sensible, latent, and total heats of evaporation of 1 lb. of steam up to a pressure of 7 atmospheres, *i.e.*, about 88 lbs. on the square inch above the atmosphere:—

—	S.	L.	H.
At pressure of 1 atmosphere . .	180	966	1146
" 2 " . .	217	940	1157
" 3 " . .	241	923	1164
" 4 " . .	259	910	1169
" 5 " . .	274	900	1174
" 6 " . .	287	891	1178
" 7 " . .	298	883	1181

We see from this table that, notwithstanding the decrease in the latent heat, *the total heat of evaporation* slowly increases. This point will be found to be of great importance in considering the expansive properties of steam, and one that will explain some curious phenomena connected therewith.

Quantity of Water required for Condensation.—Students will be shown further on the importance placed by Watt on the production of a good vacuum behind the piston of his steam engine. He thereby took as full advantage as possible of the natural pressure of the atmosphere in propelling the piston forward, and of getting as much work out of his engine as he could. In order to do so, he attached to his steam cylinder a separate chamber, called

by him a "condenser," whereby the exhausting steam, instead of going straight into the open air (and meeting with a resistance of about 15 lbs. on the square inch), was brought into intimate contact with a spray or douche of cold water, which had instantly the effect of greatly reducing its temperature, and consequently its volume and pressure, as may be observed from an inspection of the graphic diagram on p. 67; from which it will be seen that steam at atmospheric pressure occupies 1642 times the volume of its weight in water. The most economical engines of the present day are "condensing engines," and, consequently, the student will at once see the full importance of thoroughly mastering the following problems relating to the quantity of water required for condensing a known quantity of steam.

First, we shall obtain a formula or rule for determining the minimum weight of condensing water which must be directly mixed with 1 lb. of steam, in order that the mixture may be reduced to water at a certain temperature, or the temperature of the hot-well.

The following is theoretically true:—

*The Loss of Heat from the Steam = the Gain of Heat by the Water.**

Now, let 1 lb. of steam at a temp. $t_1°$ be subjected to an injection of x lbs. of water at a temp. $t_2°$, and let the result be water at a temp. $t_3°$.

Let H = total heat, reckoned from 32° F., in 1 lb. of steam at $t_1°$; then $H = 1082{\cdot}4 + {\cdot}3t_1$ B.T.U. Hence

$$\left.\begin{array}{l}\text{The } \textit{loss} \text{ of heat from 1 lb. of steam}\\ \quad\text{in falling from } t_1° \text{ to } t_3°\end{array}\right\} = 1 \times \{H - (t_3 - 32)\} \text{ B.T.U.}$$

and the *gain* of heat in x lbs. of water $= x \times (t_3 - t_2)$.

$$\therefore\ 1 \times \{H - (t_3 - 32)\} = x \times (t_3 - t_2)$$

$$\therefore\ x = \frac{H - t_3 + 32}{t_3 - t_2} = \frac{1082{\cdot}4 + {\cdot}3t_1 - t_3 + 32}{t_3 - t_2} = \frac{1114{\cdot}4 + {\cdot}3t_1 - t_3}{t_3 - t_2} \text{ lbs.,}$$

which is the general formula for the weight of water required to condense 1 lb. of steam at $t_1°$ to water at $t_3°$.

As a particular case, let $t_1 = 212°$F., then

$$x = \frac{1114{\cdot}4 + {\cdot}3 \times 212 - t_3}{t_3 - t_2} = \frac{1178 - t_3}{t_3 - t_2} \text{ lbs.}$$

An example or two will illustrate the above rule and fix the principle in the memory, as well as clearly show the difference

* In working out examples students may substitute t_s for t_1; t_w for t_2 and t_h for t_3, where s stands for steam, w for water and h for hot-well.

between the mixing of two quantities of water, and a quantity of steam and water.

EXAMPLE I.—If 1 lb. of *water* at 212° F. be mixed with x lbs. of water at 60° F., what is the value of x when the resulting temperature is 100° F.?

The Loss of Heat from the Water at 212° F. = the Gain of Heat by the Water at 60° F.

$$\therefore 1 \times (212° - 100°) = x \times (100° - 60°)\,;\ \therefore 112 = 40x, \text{ or } x = \frac{112}{40} = 2{\cdot}8 \text{ lbs.}$$

Again—If 1 lb. of *steam* at 212° F. be mixed with x lbs. of water at 60° F., what is the value of x when the resulting temperature is 100° F.?

The Loss of Heat from the Steam at 212° F. = the Gain of Heat by the Water at 60° F.

The *loss* of heat from the steam $= 1 \times \{1146 - (100 - 32)\} = 1078$ B.T.U.

The *gain* of heat by the water $= x \times (100 - 60) = 40x$ B.T.U.

$$\therefore 1078 = 40x, \text{ or } x = \frac{1078}{40} = 26{\cdot}95 \text{ lbs.}$$

We thus see the great effect of the latent heat of steam. It only requires 2·8 lbs. of water at 60° to produce the same temperature-result on *water* at 212° that 26·95 lbs. of water can do on *steam* at the *same* temperature.

EXAMPLE II.—In a jet condenser the temperature of the condensing water is 60° F., and that of the exhaust steam is 160° F. The temperature of the hot well is 110° F. Suppose the engines develop 200 I.H.P., and use $\frac{1}{2}$ lb. of steam per I.H.P. per minute, find the weight of condensing water supplied per hour to the condenser.

Here the weight of steam passing through the condenser *per hour* $= 200 \times \frac{1}{2} \times 60 = 6{,}000$ lbs. Let x = weight of condensing water required. Then *the Loss of Heat from the Steam = the Gain of Heat by the Water.*

The *loss* of heat from 6,000 lbs. of steam at 160° F.

$$= 6{,}000 \times \{H. - (100 - 32)\} \text{ B.T.U.}$$
$$= 6{,}000 \times \{1082{\cdot}4 + {\cdot}3 \times 160 - (110 - 32)\} \text{ B.T.U.}$$
$$= 6{,}000 \times 1052{\cdot}4 = 6{,}314{,}400 \text{ B.T.U.}$$

The *gain* of heat by the water $= x(110 - 60) = 50x$ B.T.U.

$$\therefore 6{,}314{,}400 = 50x\,; \text{ or } x = \frac{6{,}314{,}400}{50} = 126{,}288 \text{ lbs.} = 56{\cdot}47 \text{ tons per hour.}$$

We might have applied the formula already deduced on previous page in answering this question.

$$\text{Here} \quad x = \frac{1114{\cdot}4 + {\cdot}3 \times 160 - 110}{110 - 60} = 21{\cdot}048 \text{ lbs. per lb. of steam.}$$

$\therefore$ since there are 6,000 lbs. of steam passing through the condenser per hour, there will be 6,000 times the above quantity of condensing water required per hour

$$= 21{\cdot}048 \times 6{,}000 = 126{,}288 \text{ lbs.} = 56{\cdot}47 \text{ tons as before.}$$

Although the jet condenser has now been greatly superseded by surface condensers wherever pure fresh condensing water cannot be obtained (owing to the advantage of the condensing water being kept free from contact with the steam), we must refer students to our text-book on *Steam and Steam Engines* for the problems involved in determining the quantity of condensing water required therewith, owing to their more advanced character.

LECTURE IX.—QUESTIONS.

1. If a pound of water at 212° F. be mixed with x pounds of water at 60°, what is the value of x when the resulting temperature is 120°? Again, if a pound of steam at 212° F. be mixed with y pounds of water at 60°, find y when the resulting temperature is 120°. Account for the difference between x and y. *Ans.* $x = 1{\cdot}53$ lb.; $y = 17{\cdot}5$ lbs.

2. What is the latent heat of steam? If a quantity of steam weighing one pound, and at a temperature of 212° F., is condensed in 100 lbs. of water at 60° F., what is the resulting temperature? *Ans.* 71°·06.

3. If 2 lbs. of steam at 212° F. are passed into 30 lbs. of water at 70° F., what is the temperature of the water at the end of the operation? *Ans.* 139°·2.

4. In a jet condenser the temperature of the condensing water is 60° F., and that of the entering steam is 193° F. Also the condenser remains at a temperature of 120°. Under these conditions find the weight of condensing water per pound of steam which enters the condenser. *Ans.* 17·53 lbs.

5. How many pounds of water at 50° F. must be mixed with 1 lb. of steam at atmospheric pressure to give a temperature of 105° F. to the mixture? *Ans.* 19·5 lbs.

6. If there pass at the same time into the condenser, and from thence into the hot-well, 2 tons of water at 55° F. and 1·5 cwt. of steam at atmospheric pressure, what will be the resulting temperature? *Ans.* 95°·6 F.

7. Hot-well 105° F., injection 53°, and steam at atmospheric pressure. Required number of pounds of steam condensed by 4 cubic feet of the injection water. *Ans.* 12·1 lbs.

8. If there pass into the condenser at the same time 2 lbs. steam at atmospheric pressure and 50 lbs. water at 50° F., find the temperature of hot-well. *Ans.* 93°·38 F.

9. Using only 12 lbs. water per lb. of steam at 212° F., find the temperature of the hot-well when injection water is at 60° F. *Ans.* 146° F.

10. From 1886 Steam Examination. Temperature of injection water 60° F., temperature of hot-well 100° F., latent heat of exhaust steam 1016 units, its temperature being 140° F.; find the pounds of injection water required per pound of steam condensed. *Ans.* 26·4 lbs.

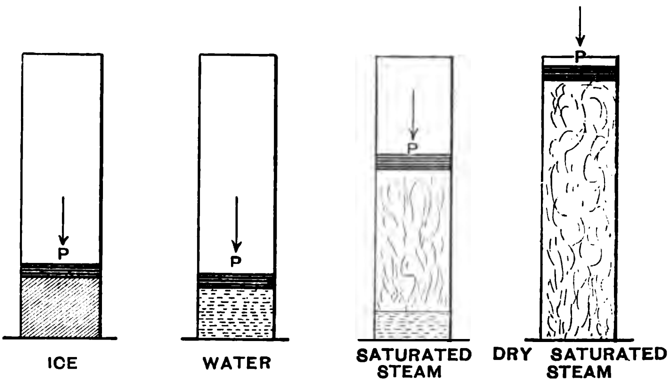
11. What is the latent heat of steam at 212°F. expressed in foot-pounds? If 1 lb. of steam at 212° F. is mixed with 10 lbs. of water at 60° F., find the resulting temperature. (S. and A. Exam., 1889.) *Ans.* 161°·6 F.

LECTURE X.

CONTENTS.—The Successive Effects produced by the Continuous Application of Heat to a piece of very cold Ice until Dissociation takes place—Definition of Wet, Dry, and Saturated Steam—The Boiling Point of a Liquid—Experiment of Water boiling at Pressures less than One Atmosphere—Use of Large Air Pumps in connection with Condensers.

WE shall best understand the physical properties of steam by considering, in the first place, the several changes which take place in water—from its solid condition, ice, until it becomes dissociated under the continuous application of heat.

These figures are purely imaginary, and not to scale.



Referring to the figure, suppose that we put 1 lb. of very cold ice in the bottom of an open-mouthed cylinder, and place a piston on it, which, together with the pressure of the atmosphere, exerts a pressure of p lbs. on the square inch.

STAGE 1.—On the application of heat to the bottom of the cylinder, the ice is gradually heated until it arrives at 32° F.

STAGE 2.—The temperature now remains constant until all the ice melts and becomes converted into water. The bulk of the water being less than that of the ice from which it is formed, the piston descends a very little. As we have already noticed in

Lecture VIII., 143 units of heat must be communicated to the 1 lb. of ice at 32° F. before it is all melted into water at 32° F.

STAGE 3.—Still applying heat, the water increases in temperature while the bulk diminishes, until 39° F. is reached (the maximum density point of water); thereafter, the volume gradually increases, but in a very slight degree, with the rise in temperature, until a little above 212° F. is reached, the limiting temperature of the water depending on the pressure p lbs. on the square inch. Had the pressure on the piston been nothing more than that due to the normal pressure of the atmosphere—viz., 14·7 lbs., corresponding to a barometric height of 29·9 inches, then the water would have been converted into steam at a temperature of 212° F.

STAGE 4.—The temperature remains stationary at that limit value, and the formation of steam commences, the piston rising as more and more of the water is evaporated. So long as any water remains at the bottom of the cylinder, we are producing what is called *saturated steam,* or wet steam. This is the condition of steam usually supplied to engines.

DEFINITION.—**Wet Steam or Saturated Steam** is *steam in contact with the water from which it is generated.* Its physical condition is such, that it is ready on the smallest increase of pressure, or decrease of temperature, to yield up or condense some portion into water, as we shall see afterwards; for a given pressure corresponds to one temperature and one volume.

STAGE 5.—When all the water in the bottom of the cylinder has been evaporated, and *just* when all the water or aqueous particles held in suspension with the steam have been converted into steam, we obtain *dry steam,* or what is sometimes termed *dry saturated steam;* then 966·6 units of heat must have passed into the contents of the cylinder, for, as we have already noticed, in Lecture VIII., 966·6 units of heat must be communicated to the 1 lb. of water before it is all converted into steam at 212° F.

DEFINITION.—**Dry Steam or Dry Saturated Steam** *is that condition of steam just at the time when all aqueous or watery particles formerly held in suspension have been converted into steam.*

STAGE 6.—If more heat be added to the dry steam in the cylinder (the total pressure, P, on the piston remaining the same), the temperature will again begin to increase, and we get what is termed *superheated steam.* The more it is heated, the more nearly do its properties approach to those of a perfect gas. If the top of the cylinder had been closed from the commencement of stage 3, the pressure would have risen with the temperature until the commencement of stage 6, in accordance with the boiling points

given below; but during stage 6 we communicate more heat to the steam than its pressure would indicate by the tables. Superheated steam is not now much used for engines, on account of its destructive action on the packing of the glands, and working surfaces of the slide valve and cylinder.

DEFINITION.—**Superheated Steam** *is that condition of steam in which, in addition to being dry, its temperature has been raised above that due to the corresponding pressure of saturated steam.* (See Pressure and Temperature Tables, Lecture XII.)

STAGE 7.—Steam cannot be heated indefinitely without a molecular change taking place, termed *dissociation*, when it separates into constituent gases—hydrogen and oxygen. This action is practically carried out in the process of making "water gas," by blowing dry steam over very hot plates before carbonizing it, ready for illuminating purposes.

Thus, the successive effects produced by the continuous application of heat to a piece of very cold ice are:—

1. Heating ice up to 32° F.
2. Melting ice, absorption of latent heat, 143 units per lb.
3. Heating water up to boiling point.
4. Formation of saturated steam, no increase of temperature.
5. Formation of dry steam, due to the complete absorption of the latent heat, or 966·6 units per lb. of water.
6. Superheated steam, increase of temperature above stage 3.
7. Dissociation or formation of hydrogen and oxygen.
8. Heating, no further alteration of the physical state.

Boiling Point.—Before discussing the "Internal and External Work done during Evaporation," we shall digress a little to consider what is meant by the boiling point.

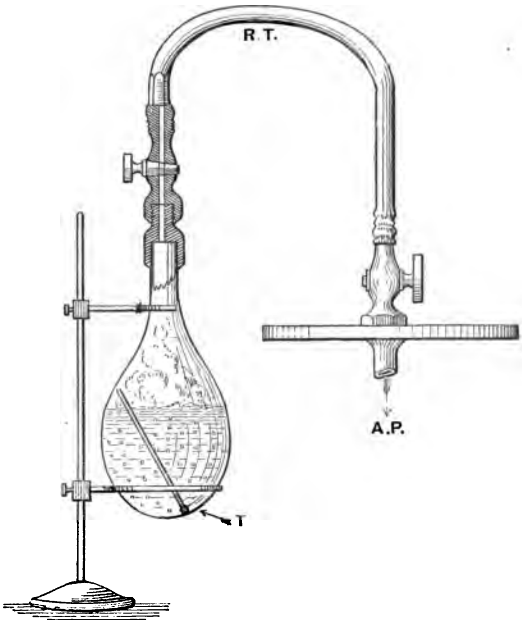
The boiling point of any liquid is that point on the temperature scale, when the tension throughout its mass just overcomes the surrounding pressure. The temperature of the boiling point, therefore, depends directly on the *pressure* under which the liquid is evaporated, and the greater the pressure the higher the temperature at which it boils.

The boiling points of fresh water at different pressures are approximately as follows:—

Under a pressure of	$\frac{1}{8}$	atmosphere	123° Fah.
"	$\frac{1}{4}$	"	150° "
"	$\frac{1}{2}$	"	179° "
"	1	"	212° "
"	2	"	249° "
"	3	"	273° "
"	4	"	291° "
"	5	"	306° "
"	6	"	319° "

It is thus clear that water will boil or give off steam far below, as well as far above, its normal boiling point, 212° F.

To illustrate this, take a glass flask half full of water with a thermometer in it, heat it over a spirit lamp or Bunsen burner until the water just begins to boil and the temperature, as registered by the thermometer, is 212° F. Now attach it, as shown, to an air-pump, A P, by a flexible india-rubber tube, and begin extracting the air. The water is observed to boil violently, although it may have cooled down to as low as 180° F. This plan of attaching it to the air-pump is much better than that of placing it under the glass-bell jar of the pump, as it permits the thermometer being easily seen after the moist steam has begun to rise.



If an air-pump be not at hand, the following simple experiment will illustrate the fact equally well to a class:—After heating the water in the flask to 212° F., and letting it boil freely for a minute to expel the air, cork it up quickly and tightly, leaving a thermometer inside. Now pour cold water on the outside of the flask, the water will at once begin to boil, although the temperature may be now below 200° F. It ceases to boil, however, if you stop

cooling it. Why? Because the tension of the vapour generated equals that of the natural tension of the water; but condense this vapour by a second application of cold water, and again it begins to boil, even with the temperature below 180° F. A knowledge of these facts is most important to the engineer, for it shows him that in the condensers of large engines, he must provide air-pumps of sufficient capacity to carry off the steam vapour generated at even low temperatures. It was but recently that an acquaintance of the author's, overlooking this point, put in a set of very small air-

pumps to a pair of marine engines which he was constructing, under the impression that all that was necessary was to lift the condensed water, and that marine engineers generally, were putting on air-pumps out of all proportion to the work to be done! He soon discovered his mistake, for, on the day of the trial trip, he could not keep up a vacuum above a few inches. In addition to the steam vapour which is generated at pressures below the atmospheric pressure, any air which may have come over with the steam at once expands on a reduction of pressure, and has to be sucked away at every stroke, otherwise it will spoil the vacuum.

The experiment of raising the boiling point by raising the pressure is easily done. Procure a flask, as in the former experiment, with a tight-fitting stop cock. Half fill the flask with water, heat it with the cock open until the water boils and all the air has been expelled, then shut the stop cock. The steam now generated rises in pressure and temperature. The increasing pressure raises the boiling point and thus stops the violent ebullition, unless heat is applied very rapidly. Allow the temperature to rise, say to 240° F., then slightly open the cock, ebullition is at once observed, although the pressure is equal to two atmospheres above a perfect vacuum. The presence of salt or dirt in water raises the boiling point for any particular pressure.

LECTURE X.—QUESTIONS.

1. Describe in your own words the several effects which take place in succession on applying heat to a lump of ice enclosed in a cylinder.

2. Distinguish between (1) wet or saturated steam, (2) dry or dry saturated steam, (3) superheated steam.

3. How many units of heat are absorbed in converting 1 lb. of water at 212° F. into 1 lb. of *dry saturated steam*? Suppose the 1 lb. of water were only converted into *wet or saturated steam*, what then? Why?

4. What is meant by the *Boiling Point* of a liquid? State the ordinary boiling point of fresh water open to the atmosphere, also when subjected to pressures of 30, 45, and 60 lbs. respectively.

5. Sketch and describe how you would illustrate that water can be made to boil below as well as above 212° F.

LECTURE X*a*.

CONTENTS.—Work Done during the Conversion of Water into Dry Steam—Definitions of Internal and External Work—Efficiency of Steam—Efficiency of High Pressure Steam—General Expressions for External and Internal Work during Evaporation—Example I.—Heat Rejected to Condenser—Example II.—Partial Evaporation—Example III.—Generation of Steam in a Closed Vessel—Questions.

Work Done during the Conversion of Water into Dry Steam.—We can now give a more definite account of the distribution of heat expended during the conversion of water into steam, and thus prepare the way for a more thorough understanding of the economical use of steam in a steam engine.

An ordinary steam engine consists essentially of—

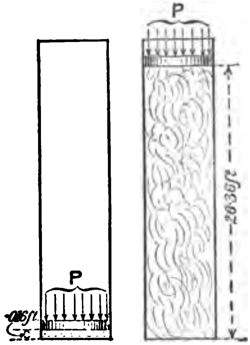
1. A *boiler* wherein the steam at a given pressure is generated from water at a given temperature.

2. A *cylinder* containing a movable, steam-tight piston, on which the steam acts and does useful work.

3. Frequently, another part, called the *condenser*, is added. The function of the condenser is exactly the opposite of that of the boiler. For in it, the steam is converted back again into water after passing through the working cylinder. Engines having only the first two essential parts are called *non-condensing*, whilst those consisting of the three parts are called *condensing* engines. These three organs are usually quite distinct and separate from each other, the connections being made by pipes, valves, &c. For our present purposes it will be best to leave out of account all connections such as pipes and valves. We shall therefore suppose the boiler, working cylinder and condenser to be one and the same vessel. Also, we shall neglect all losses of heat, such as that due to radiation, conduction, &c. Further, we shall, in the meantime, consider the case of 1 lb. of water at an initial temperature of 32° F., raised into *dry* steam at 212° F. The pressure of the steam is, therefore, that due to atmospheric pressure—viz., about 14·7 lbs. per square inch.

Take a cylindrical vessel fitted with a weightless, frictionless, and steam-tight piston, and place between the piston and the bottom of the vessel 1 lb. of water at 32° F. The cylinder being

open at the top the pressure on the piston will be constantly that due to the atmosphere. For convenience, suppose the cross



ILLUSTRATING EXTERNAL WORK DONE DURING EVAPORATION OF 1 LB. OF WATER FROM AND AT 212° F.

sectional area of the cylinder to be *one square foot* (or 144 square inches). Then,

$$\textit{Total pressure on piston} = P = 144 \times 14{\cdot}7 = 2116{\cdot}8 \text{ lbs.}$$

Since 62·5 lbs. of fresh water occupy a volume of 1 cubic foot,

$$\therefore \quad 1 \text{ lb.} \quad ,, \quad ,, \quad \text{occupies} \quad ,, \quad \frac{1}{62{\cdot}5} = {\cdot}016 \text{ cub. ft.}$$

The cross area of the cylinder being 1 square foot, it follows that the under surface of the piston will be ·016 foot above the base of the vessel.

By applying heat to the bottom of the vessel the temperature of the water will be ultimately raised to 212° F. The heat expended in this operation is $(212 - 32) = 180$ B. T. U. Now, the volume of the 1 lb. of water at the end of this operation is slightly greater than ·016 cubic foot, as shown by the graphic figure on page 67. The piston has, therefore, been raised by a small amount, and consequently work has been done in overcoming the atmospheric resistance. We thus see that rather *less* than 180 B. T. U. are employed in increasing the molecular kinetic energy of the water. This increase in the volume of the water between 32° F. and 212° F. is so small (being only $\cdot 016 \times \cdot 043 = \cdot 000688$ cubic foot (see Fig. page 67)* that it may

* The volume at 32° F. of a certain quantity of water is (as shown by the figure and text at page 67) = 1·000127, and at 212° F. = 1·043. The difference is practically = ·043. Consequently if a certain weight of water occupies about unit volume at 32° F. and increases by ·043 unit when its

safely be neglected. The piston therefore remains almost stationary between these two temperatures.

Continuing the application of heat to the water at 212° F., the water becomes evaporated and the piston rises rapidly, whilst the temperature remains constant. Suppose the source of heat to be withdrawn just when the last particle of the 1 lb. of water has been converted into dry steam. Then we know that 966·6 B. T. U. have been spent in bringing about this change. The piston will now be at a considerable height above the base of the vessel, and, consequently, a certain fraction of the *latent* heat will have been employed in doing work against atmospheric pressure. Referring to column 5 of the "Table of the Properties of Saturated Steam" on page 107, we notice that 1 lb. of *dry* steam at atmospheric pressure (temperature 212° F.) occupies a volume of 26·36 cubic feet. Hence the piston will now stand at a height of 26·36 feet above the base of the vessel. The vertical displacement of the piston is, therefore, $26{\cdot}36 - {\cdot}016 = 26{\cdot}35$ feet approximately.

$\therefore$ *Work done in raising piston* $= 2{,}116{\cdot}8 \times 26{\cdot}35$ ft. lbs.

" " " $= 55{,}777{\cdot}68$ "

Or, expressed in heat units " $= \dfrac{55{,}777{\cdot}68}{772} = 72{\cdot}25$ B.T.U.

Thus, of the 966·6 B. T. U. of *latent* heat, 72·25 B. T. U. are employed in doing mechanical work *external* to the substance (water) which is undergoing a change of state; while the remainder (894·35 B. T. U.) is spent in bringing about *internal* changes.

DEFINITION.—*The energy spent in bringing about internal or molecular changes in a substance is called* **Internal Work,** *and that spent on bodies external to the substance is called* **External Work.**

The student must carefully distinguish between *internal* and *external* work. The former represents energy *in* the substance itself, whether in the form of molecular kinetic energy or that due to change of state; the latter represents energy which has *passed out of* the substance to external bodies.

temperature is raised to 212° F., what will be the increase in volume of ·016 cubic foot of water under the same circumstances?

$$\therefore \quad 1 : {\cdot}016 :: {\cdot}043 : x.$$

$$Or, \quad x = \frac{{\cdot}016 \times {\cdot}043}{1} = {\cdot}000688.$$

The distribution of heat in converting 1 lb. of water at 32° F. into dry steam at 212° F., may be briefly stated thus—

1. *Raising temp. of water from 32° F. to 212° F.*	=	180·00 B.T.U.
2. *Internal work during evaporation* . .	=	894·35 „
3. *External work during evaporation* . .	=	72·25 „
Total Heat Expended . .	=	**1146·6 B.T.U.**

These numbers are in the proportion—180 : 894·35 : 72·25. Or, dividing by the smallest number, 72·25, the proportion is 2·5 : 12·38 : 1. We shall make use of the terms of this proportion in setting out the diagrams of work in the case under consideration.

The student knows from his study of mechanics that mechanical work can be completely represented by an area or "*diagram of work.*" When the effort or pressure is constant throughout the displacement (as in the case of the rising piston just referred to), the *diagram of work* is a rectangle, whose height represents the constant pressure, and base the given displacement. If the pressure varies during the displacement (as in the case of steam or gas expanding behind the working piston of an engine), the diagram of work will not be a rectangle, but a figure bounded by straight and curved lines. In this case, the *mean height* of the figure is a measure of the *mean pressure* exerted during the total displacement, and the length of the figure as before represents the total displacement.*

Now, heat and work being mutually convertible, it follows that quantities of heat may just as conveniently be represented by areas as quantities of mechanical work. These quantities, however, differ in this respect. In the former there is nothing corresponding to the two factors, effort or pressure and displacement, as in the case of the latter. Hence the diagram for a quantity of heat may be any shape we please, so long as it contains as many units of area as there are units of heat to be represented. It is, however, convenient for our present purposes to represent quantities of heat by rectangular areas, and if we first draw an ordinary diagram for the *external* work done during evaporation, we may then construct the *internal* work diagrams on the same base, the heights of which need only be drawn in the

* For further information and examples on the subject of graphical representation of work done by constant and by variable forces, see Lectures I. and II. of the Author's "Manual on Applied Mechanics." See also Lectures XII., XIII., XVI., and XVII., of the present work for theoretical and actual indicator diagrams of work.

proportions stated above. This should be clearly understood from what follows.

•We have seen that the expression for the external work is the product of the two factors—viz., *pressure* = 2116·8 lbs., and *displacement* = 26·35 feet.

Or, *External work* = 2116·8 × 26·35 = 55,777·68 ft. lbs.

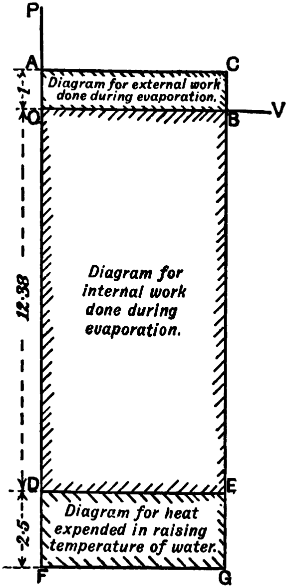


DIAGRAM SHOWING INTERNAL AND EXTERNAL WORK DONE IN CONVERTING WATER AT 32° F. INTO DRY STEAM AT 212° F.

Draw two lines O P, O V at right angles to each other. Along O P set off O A, to any convenient scale, to represent the pressure of 2116·8 lbs.; and along O V set off O B, to any convenient scale, to represent the displacement of 26·36 ft. Complete the rectangle O A C B. Then O A C B is the diagram representing the *external work* done during the evaporation of 1 lb. of water from and at 212° F. For its area is equal to O A × O B, which is thus proportional to 2116·8 × 26·36, or 55,777·68, the number expressing the ft.-lbs. of external work done.

Now, we have seen that the *internal* work done during evaporation is 12·38 times the external work. Therefore, produce P O downwards, and cut off a part O D = 12·38 × O A, and complete the rectangle O B E D. Then the area, O B E D, represents to the same scale as in the previous case, the *internal* work done during the evaporation of the water.

Similarly, on O D produced, cut off D F = 2·5 × O A, and complete the rectangle D E G F. Then the area, D E G F, represents the work done in raising the temperature of the water from 32° F. to 212° F.

Efficiency of Steam.—By returning the whole of the steam to its initial conditions—viz., water at 32° F., with the piston ·016 feet above the base of the cylinder, and repeating the above cycle of operations (heating, evaporating, condensing and cooling) over and over again, the piston will have a vertical reciprocating motion corresponding to that of an ordinary steam-engine. The *maximum external work* done during each cycle will be repre-

sented by the small rectangular area O A C B, while the total heat expended will be represented by the much larger area, A C G F. From this we can deduce the expression for the efficiency of a non-expansive engine using steam at atmospheric pressure from feed water at 32° F.* Thus—

$$\text{Efficiency} = \frac{\textbf{Heat converted into useful work.}}{\textbf{Total heat expended.}}$$

$$\text{"} \quad = \frac{72{\cdot}25}{1146{\cdot}6} = {\cdot}063, \textit{ or, } 6{\cdot}3\ \%$$

Hence, under circumstances more favourable than any occurring in practice, we see what a small percentage of the total heat expended can be usefully employed in the engine.

The efficiency just found is usually called the **Steam Efficiency,** to distinguish it from the efficiencies of the boiler and the mechanism of the engine. The *product* of the efficiencies of the boiler and the engine constitutes the efficiency of the whole combination.

By using feed water at a higher temperature than 32° F., the total heat expended per 1 lb. of water evaporated would be less than that found above, and, consequently, the steam efficiency would be slightly higher. Thus, in jet-condensing engines, the feed water has a temperature corresponding to that of the hot well; which, in the average, is about 110° F. Hence, taking steam at atmospheric pressure (as before) raised from feed water at 110° F., we may calculate the steam efficiency as follows:—

Total heat expended = *Increase of Sensible heat* + *Latent heat.*
" " = $(212 - 110) + 966{\cdot}6 = 1068{\cdot}6$ B.T.U.
External work done = $72{\cdot}25$ B.T.U. (same as before).

$$\therefore \textbf{ Steam Efficiency} = \frac{72{\cdot}25}{1068{\cdot}6} = {\cdot}0676, \textit{ or, } 6{\cdot}76\ \%.$$

This gives an increase of ·46 % over the first case.

Efficiency of High Pressure Steam.—Suppose we load the piston of the tall cylindrical vessel to such an extent that the pressure produced on the surface of the 1 lb. of water is, say, 100 lbs. per square inch absolute. From what has been already said, we know that steam will not begin to be formed (*i.e.*, the water will not boil) until the temperature is considerably higher than 212° F. The exact temperature at which evaporation commences can be found from the Table on page 107. Referring to this Table we see in columns 1 and 2 that the boiling point of water subjected

* For the more advanced problem of finding the efficiency of an expansive engine, see the Author's Text-book on "Steam and Steam Engines;" also Prof. Cotterill's book, "The Steam Engine as a Heat Engine."

to a pressure of 100 lbs. per square inch is 327·9° F., say, 328° F. To make the problem before us more practical, suppose the initial temperature of the 1 lb. of water to be 110° F.

Applying heat to the bottom of the vessel the temperature of the water rises to 328° F., at which point it remains fixed until evaporation is complete. During evaporation the piston ascends as before, but not to the same height. Referring again to the Table on page 107, we notice, in column 5, that the volume of 1 lb. of dry steam at a pressure of 100 lbs. per square inch is 4·33 cubic feet. Hence, after complete evaporation, the piston will be at a height of 4·33 feet above the base of the vessel. The total pressure on the piston is $P = 144 \times 100$ lbs.

∴ **External work done during evaporation** $= (144 \times 100) \times (4{\cdot}33 - {\cdot}016)$ ft. lbs.

" " $=$ **62,121·6 ft. lbs.**

Or, " " $= \dfrac{62{,}121{\cdot}6}{772} =$ **80·47 B.T.U.**

Total heat expended . $=$ {*Increase of Sensible heat + Latent heat.*

Increase of Sensible heat $= 328 - 110 = 218$ B.T.U.

Latent heat of steam at 328° F. (*See* p. 64.) $= 966{\cdot}6 - {\cdot}7\,(328 - 212) = 885{\cdot}4$ B.T.U.

∴ **Total Heat Expended** $= 218 + 885{\cdot}4 =$ **1103·4 B.T.U.**

∴ **Steam Efficiency** $= \dfrac{80{\cdot}47}{1103{\cdot}4} =$ **·0725**, *or*, **7·25 %**

Comparing these results with the corresponding ones for steam at atmospheric pressure, we notice that the external work in this case is only 8·22 B. T. U. more than in the former case. This corresponds to an increase of about 10 %. The increase in the steam efficiency, however, is but 7·25 − 6·76, or ·49 %.

The student may therefore naturally ask, wherein lies the advantage of using high pressure steam? In answer to this question, we should first of all remind him that the engine under consideration is a *non-expansive* one. That is, the steam acts on the piston with its full pressure throughout the whole stroke. Consequently, high pressure steam would not be adopted except as a means of increasing the power of such an engine without increasing its size. For, the use of high pressure necessitates the employment of stronger boilers and cylinders, as well as greater accuracy in construction. It is only where steam is used expansively that high pressures can be economically and efficiently adopted.*

* The advantages of using steam expansively will be quite apparent after studying Lectures XII. and XIII.

In drawing the above comparison between the performances of the two engines (the one using low-pressure and the other high-pressure steam) we have taken equal *weights* of steam. The results of the comparison would, however, be very different if we had taken equal *volumes*. Thus, it is quite clear that steam at 100 lbs. pressure, when used non-expansively in a cylinder of given volume, would perform $\frac{100}{15} = 6{\cdot}\dot{6}$ times more work than steam at atmospheric pressure under like circumstances in the same cylinder. But, then, the *weights* of steam used in the two cases would be very nearly in the proportion $6{\cdot}\dot{6} : 1$, and the fuel consumed would be in the same proportion. Now, the object of the engineer is to obtain the greatest amount of work for the least possible consumption of fuel, and, consequently, the comparison between the performances of two engines should be made with respect to the weights of steam used for a given amount of work performed. Nevertheless, it is sometimes necessary to know the work done per cubic foot of steam used. This may be obtained by dividing the work done per lb. of steam by the volume of 1 lb. of steam at the given pressure. Thus—

$$\left.\begin{matrix}\textit{Work done per cub. ft. of}\\ \textit{steam at atmos. pressure.}\end{matrix}\right\} = \frac{\textit{External work during evaporation.}}{\textit{Volume of 1 lb. of steam.}}$$

$$\text{,,} \qquad \text{,,} \qquad = \frac{55{,}777{\cdot}68}{26{\cdot}36} = 2116 \text{ ft. lbs.}$$

General Expressions for External and Internal Work during Evaporation.—We shall now express the preceding results in general terms—

Let t_1 = Temperature of steam.
,, t_2 = Temperature of feed water.
L = Latent heat at temperature t_1.
,, p = Pressure of steam in lbs. per square inch.
,, V_s = Volume in cub. ft. of 1 lb. of *dry* steam at pressure p.*
,, V_w = ,, ,, ,, water = ·016 cub. ft.

Supposing the steam to be *dry*, then, we have—

1. **Total heat expended** = $\left\{\begin{matrix}\textit{Increase of Sensible heat}\\ \textit{+ Latent heat.}\end{matrix}\right.$ (*See* LECTURE IX.)

$$\text{,,} \quad \text{,,} \quad = (t_1 - t_2) + L,$$
$$\text{,,} \quad \text{,,} \quad = (t_1 - t_2) + 966{\cdot}6 - {\cdot}7\,(t_1 - 212) \text{ B.T.U.}$$
$$\text{,,} \quad \text{,,} \quad = \mathbf{1115 + {\cdot}3t_1 - t_2 \text{ B.T.U.}}\dagger$$

* The volume of 1 lb. of dry steam at a given pressure is sometimes called the *Specific Volume* of steam at that pressure. We find, however, that students often make the mistake of confounding the term *Specific Volume* with that of "Relative Volume of Equal Weights of Steam and Water," and, therefore, we prefer not to use the former term.

† Instead of remembering this final result, students should deduce it, when required, from definition as stated in italics above.

2. **External work done during evaporation** $= \left\{ \begin{array}{l} \textit{Pressure per sqr. ft.} \times \textit{Increase of} \\ \textit{volume during evaporation.} \end{array} \right.$

$$,, \quad ,, \quad = 144\,p\,(V_s - V_w) \text{ ft. lbs.}$$

$$\text{Or,} \quad ,, \quad ,, \quad = \frac{144\,p\,(V_s - V_w)}{772} \text{ B.T.U.}$$

3. **Internal work done during evaporation.** $=$ *Latent heat – External work.*

$$,, \quad ,, \quad = 966{\cdot}6 - {\cdot}7\,(t_1 - 212) - \frac{144\,p\,(V_s - V_w)}{772} \text{ B.T.U.}$$

The value of V_w, in the expression for external work is so small compared with that of V_s for all ordinary pressures, that we may safely neglect it in most calculations.

EXAMPLE I.—How many ft.-lbs. of work are done in converting 1 lb. of water from a temperature of 100° F. into dry steam at 281° F. (corresponding to an absolute pressure of 50 lbs. per square inch)? The volume of 1 lb. of dry steam at that temperature and pressure being 8·31 cubic feet; find external and internal work done during formation of steam, and weight of steam used per hour per horse power.

ANSWER. — Here, $t_1 = 281°$F., $t_2 = 100°$F., $p = 50$ lbs. per square inch, $V_s = 8{\cdot}31$ cubic feet.

1. *Total heat expended* $= \left\{ \begin{array}{l} \textit{Increase of sensible heat} \\ + \textit{Latent heat.} \end{array} \right.$

Increase of sensible heat $= 281 - 100 = 181$ B.T.U.

Latent heat $= 966{\cdot}6 - {\cdot}7\,(281 - 212) = 918{\cdot}3$ B.T.U.

Total heat expended $= 181 + 918{\cdot}3 = \mathbf{1099{\cdot}3}$ **B.T.U.**

,, ,, $= 1099{\cdot}3 \times 772 = \mathbf{848{,}659{\cdot}6}$ **ft. lbs.**

2. **External work done during evaporation** $= 144\,p\,V_s$.

,, ,, $= 144 \times 50 \times 8{\cdot}31 = \mathbf{59{,}832}$ **ft. lbs.**

3. **Internal work done during evaporation** $= \left\{ \begin{array}{l} \textit{Latent heat of evaporation} \\ - \textit{External work.} \end{array} \right.$

,, ,, $= 918{\cdot}3 \times 772 - 59{,}832$ ft. lbs.

,, ,, $= \mathbf{649{,}095{\cdot}6}$ **ft. lbs.**

4. Let x = Weight of steam used per hour per horse power.

External work done per 1 lb. of steam formed $= 59{,}832$ ft. lbs.

∴ ,, ,, x lbs. ,, ,, $= 59{,}832\,x$ ft. lbs.

Now, 1 horse-power corresponds to $33{,}000 \times 60 = 1{,}980{,}000$ ft. lbs. per hour.

∴ By the conditions of the question—

$$59{,}832x = 1{,}980{,}000$$

$$\text{Or,} \quad x = \frac{1{,}980{,}000}{59{,}832} = \mathbf{33 \text{ lbs.}}$$

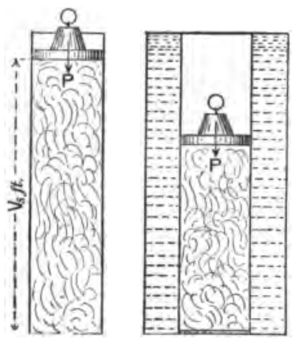
Heat Rejected to Condenser.—In the preceding examples it has been tacitly assumed that during the return motion of the piston within the cylinder, the condensation of the steam was effected under *zero* pressure—*i.e.*, condensation was so perfect that no *back pressure* was felt on the under surface of the piston. The piston, therefore, returned unloaded. The whole of the external

work done during the upward motion of the piston was, therefore, available for useful purposes. Had the condensation been incomplete, part of the work would have been employed in returning the piston against the back pressure due to the imperfect vacuum. Such perfect conditions as we have hitherto assumed cannot be attained in practice. Condensation is always more or less imperfect, and consequently we find that the back pressure *varies* from 2 to 5 lbs. per square inch in condensing engines, to 15 or 18 lbs. per square inch in non-condensing engines. A perfect vacuum cannot be attained in practice; for, water at all temperatures gives off vapours which naturally exerts a certain pressure. Thus, at a temperature of about 80° F. water vapour exerts a pressure of about ·5 lb. per square inch, and at a temperature of 102° F. the vapour pressure is 1 lb. per square inch.

The subject presently before us is to determine the amount of heat rejected to the condensing water per lb. of steam passing through the engine. This, as may be inferred from the above remarks, depends upon the conditions under which condensation takes place. Consideration of the following three cases will give the student a clear idea of the distribution of heat in an ordinary steam engine:—

FIRST CASE.—*Suppose condensation to take place under the same pressure as the evaporation.*

Let p = Pressure of steam in lbs. per square inch absolute.
„ V_s = Volume of 1 lb. of dry steam at pressure p.
„ Q = Total heat expended per lb. from feed water temperature to steam at pressure p.
„ R = Rejected heat to condenser.



EXTERNAL WORK DONE DURING CONDENSATION OF STEAM UNDER THE SAME PRESSURE AS THE EVAPORATION TOOK PLACE.

As before, let the 1 lb. of water be heated under the movable piston of a tall cylindrical vessel whose cross sectional area is one square foot. For our present purposes, however, it is best to neglect the atmospheric pressure on the upper surface of the piston, and to suppose the necessary pressure to be caused by a weight placed on the piston. The magnitude of this weight will be, $P = 144\,p$ lbs.

After the water is completely evaporated, the piston will be at a height of V_s feet above the base of the vessel, and—

The external work done during evaporation $= PV_s$ ft. lbs.

$$\text{,,}\qquad\text{,,}\qquad\text{,,}\qquad\text{,,}\qquad = \frac{PV_s}{772}\ \text{B.T.U.}$$

Suppose we now convert the tall cylinder into a condenser by surrounding it with cold water. The weight P, still remaining on the piston, condensation will take place under the same conditions that evaporation took place—viz., under a pressure of p lbs. per square inch. Let the final temperature of the condensed steam be the same as the initial temperature of the water. Then, during condensation, the heat rejected to the condensing water is clearly equal to the total heat expended, or Q units. For the heat rejected is derived from the following sources:

1. That heat which is derived from the work done by the descending piston. Neglecting the very small volume V_w of 1 lb. of water, we see that the work thus converted into heat is $\frac{P.V_s}{772}$ B.T.U., which passes through the steam into the condensing water.

2. The heat formerly spent on *internal work* during evaporation is now yielded up to the condensing water.

3. The *sensible heat* given out during the cooling of the water to its initial temperature.

Hence, in a cycle of operations of this kind, no *available* external work is done. The external work done during the ascent of the piston is undone, or has to be restored during its descent, thus leaving no work available for useful purposes.

The results of this case may be stated thus:

Heat Rejected to Condenser = *Total Heat Expended.*

Or, $$R = Q.$$

SECOND CASE.—*Suppose condensation to take place under zero pressure.*

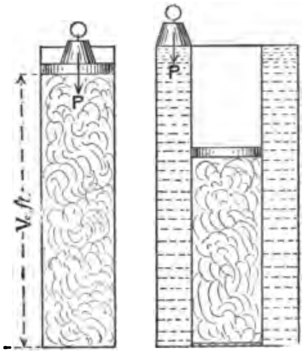
This corresponds to those cases previously considered, and also to the case of an engine whose condenser gives a perfect vacuum, or no back pressure.

To understand this case, suppose at the instant the condenser is applied to the cylinder full of dry steam that the weight P is lifted off the piston. Then, clearly, no *external work* will be done by

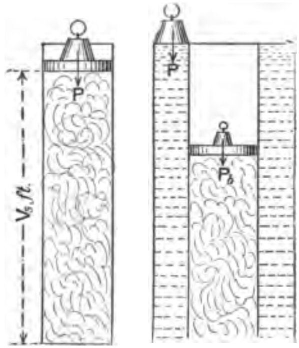
the descending piston during the condensation of the steam. Hence, in this case—

$$\textit{Heat rejected to Condenser} = \begin{cases} \textit{Total Heat Expended} \\ \quad - \textit{External Work.} \end{cases}$$

Or, $$R = Q - \frac{PV_s}{772}$$



CONDENSATION OF STEAM AT ZERO PRESSURE.



CONDENSATION OF STEAM UNDER A BACK PRESSURE OF p_b LBS. PER SQUARE INCH.

THIRD CASE.—*Suppose condensation to take place under a pressure of p_b lbs. per square inch absolute.*

This corresponds to those cases occurring in practice, where p_b is the *back pressure* on the piston due to the pressure of the vapour in the condenser.

At the instant when condensation is about to take place, imagine the weight P to be lifted off the piston and another but smaller weight ($P_b = 144\, p_b$ lbs.) to be put in its place. Then, during condensation, the piston descends under the load P_b lbs., and the work done during the descent is converted into heat, which passes away to the condensing water. The heat rejected to the condenser is therefore greater in this than in the former case by the amount $P_b V_s$ ft.-lbs., or $\frac{P_b V_s}{772}$ B.T.U.

$$\therefore\ R = Q - \frac{PV_s}{772} + \frac{P_b V_s}{772} \text{ B.T.U.}$$

$$\textit{i.e. } R = Q - \frac{(P - P_b)\, V_s}{772} \text{ B.T.U.}$$

Or, since $P = 144\, p$, and $P_b = 144\, p_b$,

$$R = Q - \frac{144}{772}(p - p_b)\, V_s \text{ B.T.U.}$$

The foregoing results could have been obtained at once from the *Principle of the Conservation of Energy*, thus—

$$\textbf{Total heat expended} = \begin{cases}\text{Heat converted into useful work}\\ +\text{heat rejected to condenser.}\end{cases}$$

But, *Total heat expended* $= Q$ units.

Heat converted into useful work $= \dfrac{(P - P_b)\,V_s}{772} = \dfrac{144}{772}(p - p_b)\,V_s$ units.

Heat rejected to condenser $= R$ units.

$$\therefore \qquad Q = \frac{144}{772}(p - p_b)\,V_s + R \text{ (heat units).}$$

As already explained, the back pressure in condensing engines varies from 2 lbs. to 5 lbs. per square inch. In non-condensing engines the steam, after performing work in the cylinder, exhausts into the atmosphere, and the back pressure can therefore never be less than the atmospheric pressure, in fact it varies from 15 to 18 lbs. per square inch. In this case the atmosphere is the condenser, but the whole of the heat rejected to it is lost. The advantages of a good condenser are thus apparent. For, in addition to the reduction of the back pressure, part of the heat rejected to it is employed in raising the temperature of the feed water.

EXAMPLE II.—A non-expansive condensing steam engine is supplied with steam at a pressure of 45 lbs. per square inch by gauge. The vacuum gauge indicates a pressure of 2 lbs. per square inch in the condenser. Find (1) the amount of heat rejected to the condenser per lb. of steam used; (2) the steam efficiency; and (3) the weight of water used per hour per effective horse-power. Let the temperature of feed water = 100° F.

ANSWER.—The *absolute* pressure of the above steam is $45 + 15 = 60$ lbs. per square inch. Referring to the tables on p. 85, we find the temperature of steam at 60 lbs. absolute to be 292·7° F., say, 293° F.; and the volume of 1 lb. of dry steam at the same pressure is $V_s = 7$ cubic feet.

$$\therefore \quad \left.\begin{matrix}\textit{Total heat expended}\\ \textit{per lb. of steam}\end{matrix}\right\} = \textit{Increase of Sensible heat} + \textit{Latent heat.}$$

Or, $Q = (293 - 100) + 966{\cdot}6 - {\cdot}7\,(293 - 212)$ B.T.U.

„ $= 1103$ B.T.U. (very nearly).

$$\left.\begin{matrix}\textit{Heat converted into Useful}\\ \textit{Work per lb. of steam}\end{matrix}\right\} = \frac{144}{772}(p - p_b)\,V_s.$$

$$\text{„} \qquad \text{„} \qquad = \frac{144}{772}(60 - 2) \times 7 = 75{\cdot}75 \text{ B.T.U.}$$

Now, $Q = \dfrac{144}{772}(p - p_b)\,V_s + R,$

$\therefore$ $\mathbf{R = 1103 - 75{\cdot}75 = 1027{\cdot}25}$ **B.T.U.**

$$\textbf{Steam Efficiency} = \frac{75{\cdot}75}{1103} = {\cdot}0687, \textit{ or, } 6{\cdot}87\%.$$

Let x = weight of water used per hour per effective h.p.

Then, $\left.\begin{array}{r}\textit{Useful work done per} \\ \textit{x lbs. of water used}\end{array}\right\} = 144\,(p - p_b)\,V_s \div x$ ft. lbs.

$\quad$ " $\quad$ " $\quad = 144\,(60 - 2) \times 7 \div x = 58{,}464\,x$ ft. lbs.

But, $\quad$ 1 *Horse-power* $= 33{,}000 \times 60 = 1{,}980{,}000$ ft. lbs. per hour.

$\therefore \quad 58{,}464\,x = 1{,}980{,}000.$

$$\therefore \quad x = \frac{1{,}980{,}000}{58{,}464} = \mathbf{34{\cdot}4\ lbs.}$$

Partial Evaporation.—Up till now, our calculations, &c., have been based on the assumption that the steam when formed contained no suspended moisture. In other words, the steam was assumed to be perfectly *dry*. The steam supplied to an engine from an ordinary boiler is seldom in this condition, for it is always more or less saturated with watery particles. Even if the steam be dry on leaving the boiler, it may enter the working cylinder in a very moist condition, due to loss of heat from various causes in its passage from the former to the latter. Again, large quantities of water sometimes pass along with the steam from the boiler to the cylinder, and go through the engine without yielding any return for the heat spent in raising its temperature to that of the accompanying steam. Such large quantities of water are called *priming*, in distinction to the smaller quantities which are mingled with the steam in the form of a fine spray and which we have termed *suspended moisture*. Priming is generally the result of either too small a steam space in the boiler or too rapid ebullition, or impurities in the water, or a combination of these defects. It may cause a great deal of trouble to the engineer in charge, and when excessive, it may result in a fractured cylinder-cover or necessitate the stoppage of the engine.

At present we are, however, not concerned with the effects of priming, and shall consequently confine our remarks to cases of partial evaporation in which the steam contains moisture held in suspension.

Take the case of 1 lb. of water at 212° F. converted into *wet* steam at the same temperature. Suppose the steam contains 10 per cent. of suspended moisture. Then only 90 per cent., or ·9 lb. of the water will be in the form of *dry* steam. Hence, instead of spending the 966·6 B.T.U. of latent heat, we only require $\cdot 9 \times 966{\cdot}6 = 869{\cdot}94$ B.T.U. to bring about this result. The fraction, ·9, is called the *dryness fraction* of the steam. If the 1 lb. of water had had an initial temperature less than 212° F., say, 100° F., then, the total heat expended would havebeen $(212 - 100) + \cdot 9 \times 966{\cdot}6 = 981{\cdot}04$ B.T.U. Generally—

Let Q = Total heat expended per lb. of *wet* steam at temperature $t_1°$ from water at temperature $t_2°$.

" L = Latent heat per lb. of *dry* steam.

" x = Dryness fraction, or *dry* steam in 1 lb. of wet steam.

Then, Q = *Increase of sensible heat + latent heat.*

But, *Increase of sensible heat* $= t_1 - t_2$ *heat units,*

And, *Latent heat per lb. of wet steam formed* $\Big\} = x\ L$, *heat units.*

Therefore, $\mathbf{Q = (t_1 - t_2) + x\ L}$ **heat units.**

We have now to show how the *external work* done during the formation of *wet* steam is found.

Let V_s = Volume of 1 lb. of *dry* steam at pressure p lbs. per square inch.

V_{ws} = Volume of 1 lb. of *wet* steam at same pressure.

V_w = Volume of 1 lb. of water = ·016 cub. ft.

x = Dryness fraction (as before).

Then, V_{ws} = (*vol. of dry steam + vol. of water*) in 1 lb. of the mixture.

$$\text{"} = x\ V_s + (V_w - xV_w),$$

Or,
$$\left.\begin{aligned}\mathbf{V_{ws}} &= \mathbf{xV_s + (1 - x)\ V_w}\\ \text{"} &= \mathbf{x\ (V_s - V_w) + V_w}\end{aligned}\right\}$$

Supposing, then, the piston of the cylinder to be one square foot in area, we get—

Displacement of piston $= V_{ws} - V_w$ ft.

∴ **External work per lb. of wet steam formed.** $\Big\} = 144\ p\ (V_{ws} - V_w)$

" " $= 144\ p\ x(V_s - V_w)$ **work units.**

Unless for very high pressures, V_w is very small compared with V_{ws}, and may, therefore, be neglected in the above formulæ.

EXAMPLE III.—A boiler supplies steam at a pressure of 90 lbs. absolute, which contains 10 per cent of suspended moisture. The temperature of the feed water is 100° F. Find (1) volume per lb. of wet steam thus formed; (2) the external and internal work during evaporation; and (3) the total heat expended per lb. of steam used.

ANSWER.—Here, p = 90 lbs. abs., and temperature corresponding to this pressure is

$$t_1 = 320°\text{ F.};\ t_2 = 100°\text{ F.};\ x = \frac{100 - 10}{100} = \cdot 9.$$

Volume of 1 lb. of *dry* steam at pressure p is Vs = 4·79 cub. ft.

From above formulæ, we get—

1. **Volume of 1 lb. of wet steam.** $= V_{ws} = x (V_s - V_w) + V_w$

$= \cdot 9 (4\cdot 79 - \cdot 016) + \cdot 016 =$ **4·312 cub. ft.**

2. **External work done per lb. of wet steam** $= 144 p (V_{ws} - V_w)$,

$= 144 \times 90 (4\cdot 312 - \cdot 016)$ ft. lbs.

$=$ **55,728 ft. lbs.**

Or, " " $= \frac{55{,}728}{772} =$ **72·2 B.T.U.** *approximately.*

3. **Internal work done during evaporation.** $=$ {*Latent heat per lb. of wet steam – external work.*

" " $= x L - \frac{144 p (V_{ws} - V_w)}{772}$ heat units.

" " $= \cdot 9 \times \{966\cdot 6 - \cdot 7 (320 - 212)\} - 72\cdot 2$ B.T.U.

" " $= 801\cdot 9 - 72\cdot 2 =$ **729·7 B.T.U.**

4. **Total heat expended per lb. of wet steam formed.** $=$ {*Increase of sensible heat + latent heat.*

" " $= (t_1 - t_2 + x$ L.

" " $= (320 - 100) + 801\cdot 9 =$ **1022 B.T.U.** *approximately.*

Generation of Steam in a Closed Vessel.—Having thus considered the whole process of the generation of steam under constant pressure, we shall now explain, briefly, the differences between those cases and the generation of steam in a closed vessel. This will be of interest to the student since it corresponds to the case of getting up steam in a boiler.

Suppose that we have 1 lb. of water at a given temperature enclosed in a vessel of large capacity. Suppose, further, that the only pressure on the surface of the water is that due to the pressure of its own vapour.

By applying heat to the bottom of the vessel, the temperature of the water rises as before, steam is generated and its pressure increases with its temperature. In previous cases, where the water was heated and evaporated under a loaded piston, no evaporation took place until the natural tension within the mass of water was sufficiently great to overcome the superincumbent pressure. In the present case, however, the surrounding pressure is always in equilibrium with the tension within the mass of water, and, consequently, evaporation goes on uninterrupted.

Suppose the capacity of the vessel to be 26·36 cubic feet (the volume occupied by 1 lb. of dry steam at atmospheric pressure). Then, when the temperature of the mass has risen to 212° F., the whole of the water will be converted into *dry* steam, and its pressure will be 14·7 lbs. per square inch absolute. Further application of heat causes superheating of the steam. Similarly, if the vessel had a capacity of 7 cubic feet (the volume occupied

by 1 lb. of dry steam at a pressure of 60 lbs. per square inch absolute), then complete evaporation would not occur until the temperature was 293° F., and the pressure of the 1 lb. of dry steam thus formed would be 60 lbs. per square inch absolute.

In getting up steam in an ordinary boiler, the pressure on the surface of the water at the commencement is usually equal to that of the atmosphere. On applying heat the temperature will rise, evaporation, or generation of steam, will not commence at once, but will be delayed until the temperature has risen to 212° F. after which the evaporation will proceed as described above.

We have seen that during evaporation under constant pressure, a fraction of the total heat expended is transformed into external work. But, by the nature of the present case, no such external work can be done, and this constitutes the essential difference between the two modes of forming steam. Now, it is quite impossible to conceive of any difference in the internal energy of 1 lb. of dry steam formed according to either method, so long as the pressures are equal. Hence we conclude, *that the total heat expended in evaporating water in a closed vessel is less, by the amount due to external work, than that spent in producing the same final result by evaporating under a constant pressure.*

It is true that during evaporation of the water in the closed vessel, work is being continually spent in compressing the steam already formed; this work, however, is done *within* the mass itself, and is but part of the *internal work.*

QUESTIONS.

1. How many foot lbs. of work and units of heat are absorbed in converting 5 lbs. of water at 32° F. into *dry steam* at atmospheric pressure? Illustrate your answer by diagrams similar to that given in the Lecture, showing the internal and external work done on the water by the heat. *Ans.* 5733 B.T.U.; 4,428,000 ft. lbs.

2. Define the terms "Internal Work," and "External Work," with reference to the generation of steam. How is the efficiency of a steam engine expressed? Illustrate your answers by taking an example and working out the various quantities arithmetically.

3. A boiler generates dry steam at an absolute pressure of 95 lbs. per square inch from feed water at 60° F. What percentage of heat will be saved by a feed-heater which raises the temperature of the feed water to 212° F.? *Ans.* 13 per cent.

4. A non-expansive engine uses steam at an absolute pressure of 60 lbs. per square inch, and makes 60 double strokes per minute. The area of the piston is 1 square foot, and the length of the stroke is 12 inches. Find (1) Weight of steam used per minute; and (2) Total heat expended per minute, the temperature of the feed water being at 60° F. *Ans.* (1) 17·12 lbs.; (2) 19,530 B.T.U.

5. A lb. of water at 60° F. is converted, at constant pressure, into dry steam at 75 lbs. per square inch absolute. Find (1) Total heat expended; (2) External work done during evaporation; (3) Internal work done during evaporation; (4) Work done in raising temperature of water. Construct a diagram showing graphically these various quantities of work. *Ans.* (1) 1148·35 B.T.U.; (2) 79·72 B.T.U.; (3) 821·13 B.T.U.; (4) 247·5 B.T.U.

6. Suppose, in Question 5, that the 1 lb. of water has been converted into wet steam containing 10 per cent. of suspended moisture. Find (1) Internal work; (2) External work done during evaporation. *Ans.* (1) 738·27 B.T.U.; (2) 71·73 B.T.U.

7. A boiler supplies steam with 10 per cent. of suspended moisture, the evaporation taking place at 320° F. from feed water at 100° F. Find total heat expended per 1 lb. of steam formed, and the weight of water which could be evaporated from and at 212° F. for the same expenditure of heat. *Ans.* 1022 B.T.U.; 1·056 lbs.

8 An engine works non-expansively with condensation. The initial pressure of the steam is 25 lbs. by gauge, and the back pressure is 3 lbs. absolute. Temperature of feed water 104° F. Find (1) Effective work per lb. of steam used; (2) Weight of steam used per hour per H.P.; (3) Total heat expended per hour per H.P.; (4) Steam efficiency; and (5) Heat rejected to condenser per lb. of steam used. *Ans.* (1) 69·6 B.T.U. (2) 37 lbs. nearly; (3) 40,381·8 B.T.U.; (4) 6·5 per cent.

9. Distinguish between heat and temperature. What are the units by which each is measured? How many units of heat are required for raising 1 lb. of water from 32° F. to 212° F., and then for evaporating it into steam? How much mechanical work would be done in each operation? (S. & A. Exam. 1895).

10. What is meant by "Sensible Heat," "Latent Heat," and "Total Heat of Evaporation"? Calculate the total heat in British Thermal Units required to convert 30 lbs. of water at 62° F. into steam at a temperature of 212° F. If a pound of coal develops 14,000 units of heat during its combustion, how many pounds of coal would be required to convert the 30 lbs. of water into steam under the above conditions, if there was no loss of heat in the operation? (S. & A. Exam. 1896).

LECTURE XI.

CONTENTS.—Temperature and Pressure of Steam—Marcet's Boiler—Graphic Curve of Pressures and Temperatures—Mercurial Pressure and Vacuum Gauges—Bourdon's and Schäffer's Pressure and Vacuum Gauges—Pressure Pyrometer or Thalpotasimeter.

Temperature and Pressure of Steam.—When water is confined in a closed vessel, and heated, the pressure of the vapour contained therein continually increases. The precise temperature which corresponds to any particular pressure, has been made the subject of very careful inquiry by Regnault and others.

We shall now illustrate these phenomena by means of a simple apparatus, termed Marcet's boiler. On applying heat from the Bunsen burner, B B, steam is generated from the water, W, and the temperature as it rises is noted by the thermometer, T. Simultaneously, the column of mercury rises in the tube, and the height from the free surface of the mercury may be read off (roughly) on the graduated scale, G S. Since the tube, G T, is open at the top, when the temperature has arrived at 233° F., the mercury will be observed to have risen about 15 inches, corresponding to a pressure of 7·4 lbs. above the atmosphere, or a total pressure of 22 lbs. per square inch. This is usually termed 22 lbs. absolute.* When the temperature arrives at 250° the mercury will have risen to about 30 inches, corresponding to a pressure of 14·7 lbs. on the square inch (1 atmosphere), or 29·4 lbs. absolute (*i.e.*, 14·7 lbs. above the atmosphere + 14·7 for the atmospheric pressure).

If our glass tube had been longer, and the supply of mercury in the bottom of the boiler sufficient, we might have gone on applying heat and registering still higher pressures with their corresponding temperatures, but the limited experiment has been

* *Absolute pressures*, are pressures reckoned from a perfect vacuum as 0, or zero; whilst *ordinary pressures*, as indicated by steam gauges, &c., are pressures reckoned from the atmospheric pressure at the place as zero, and they, therefore, require about 15 lbs. to be added to them in order to convert them into absolute, or total pressures. In all questions relating to the temperature and expansion of steam, absolute pressures are used in this book.

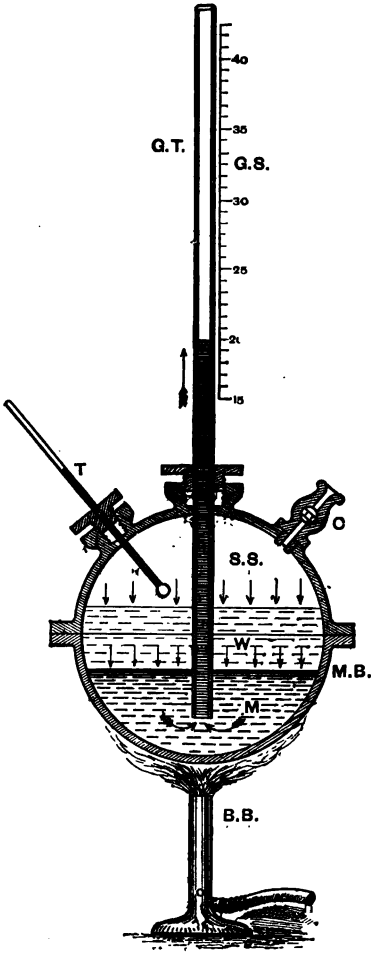
sufficient to show roughly, that a rise in temperature cannot take place without a corresponding rise in pressure. Mercurial gauges, such as that in the Marcet's boiler, were much used to register the pressure of steam in steam boilers, before the introduction of the Bourdon gauge.

The following curve illustrates the way in which the pressure of saturated steam rises with its temperature. It is plotted out from the table in Lecture XII.

When any two physical conditions (such as the temperature and the pressure of steam in the case we have been considering) vary with respect to each other, it forms a useful exercise, as well as impresses the fact upon the student, if he plots out graphically the corresponding quantities to scale. In the next figure, the absolute pressures are divided off to scale on the vertical line from 15 to 100 lbs., while the corresponding temperatures are pitched to scale on the horizontal line. The intersection of the horizontally drawn dotted lines and the vertically drawn dotted lines from each of the corresponding quanti-

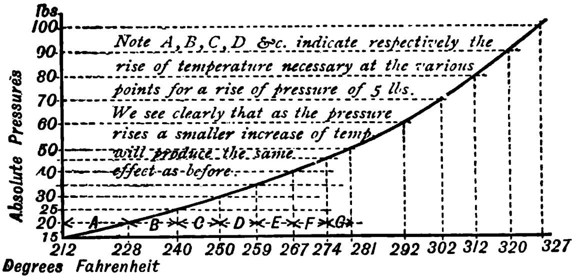
INDEX TO PARTS.

B B for Bunsen burner.
M B „ Marcet's boiler.
M „ Mercury.
W „ Water.
S S „ Steam space.
T „ Thermometer in S S.
G T „ Glass tube, about 35 in. long.
G S „ Graduated scale.
C „ Cock.



MARCET'S BOILER.

ties gives us points on the curve. If these intersections are now joined by a firm line we obtain the desired curve.



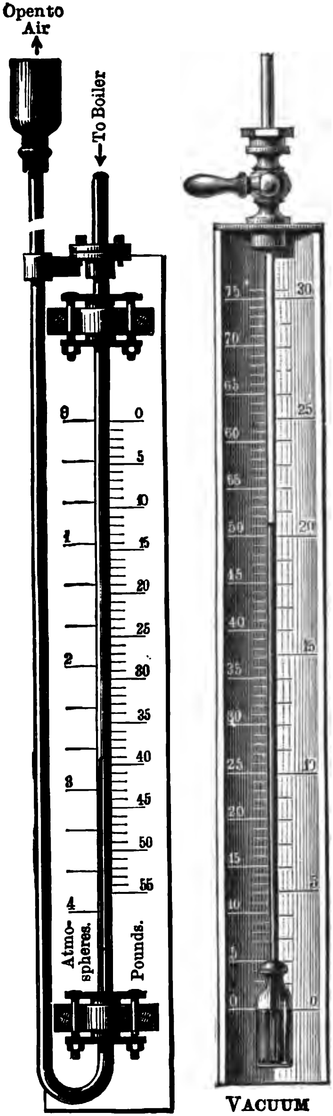
CURVE OF PRESSURES AND TEMPERATURES.

Pressure Gauges.—Instruments for indicating the intensity of the pressure of a fluid contained in a closed vessel, are called "pressure gauges," or "vacuum gauges," according as they register how much the pressure is above or below that of the atmosphere. As we shall see later on in the case of the "Indicator," that instrument is adapted for registering pressures both above and below the atmospheric pressure.

The Mercurial Pressure Gauge, as seen by the following figure, consists of a bent, U, glass tube, containing mercury, from O to O, round the bend of the tube. One end is connected directly to the closed vessel, or say to a steam boiler, while the other end is connected to a cup, to prevent the mercury being lost when the pressure rises higher than the range of the tube. This cup is open to the air, and consequently the pressure of the atmosphere acts on that side of the mercurial column. A vertical scale is fixed immediately behind the vertical limb connected to the boiler or closed vessel, and it is graduated in any convenient manner—say, for lbs. per square inch of pressure. As the pressure increases, the mercury in this limb is depressed, and rises correspondingly in the other limb. When the pressure in the closed vessel equals that of the atmosphere, both free ends of the mercury should stand at 0. The reading on the first following cut shows a pressure of 39 lbs. Nothing could be simpler or more accurate than this arrangement, for, as we saw in the case of the Marcet's boiler, a vertical column of mercury produces a definite pressure of about 1 lb. per square inch for every 2 inches in height. In practice, however, the inside of the glass tube gets coated with a dirty film, owing to the oxidation of the mercury, which prevents the attendant observing the exact position of the depressed end of the mercurial column.

Such a pressure gauge is, of course, inadmissible on board a ship or on a locomotive, owing to the jerking motion; and further, the length of the tube would have to be very great for the pressures now carried in high-pressure steam boilers (about 300 inches, or 25 feet for 150 lbs. on the square inch). For these reasons its use has been discarded in ordinary practice; but, as an exact and standard instrument for scientific purposes, and for testing and graduating the working pressure gauges (which we are about to describe), it is indispensable. In all the best works where ordinary pressure gauges are made and tested, there is, therefore, fixed a long vertical mercury column or gauge, with which these may be compared, and there the inside of the glass is occasionally rubbed clean by a little cotton-wool dipped in sulphuric acid, and fastened to the end of a wire.

Mercurial Vacuum Gauge.—This gauge indicates directly the *absolute* pressure inside a vessel such as the condenser of a steam engine, the suction pipe to an air-pump, or the vacuum pan of a sugar-refinery. The simplest form in which it is made is illustrated by the second figure. It consists of a vertical glass tube a little over 30 inches in length, with its lower end open and dipping into an iron pot containing mercury, while its upper end is attached to a brass cock and pipe connected with the vessel or condenser. A scale is fixed behind the glass tube,



PRESSURE GAUGE. VACUUM GAUGE.

graduated on the right hand into inches, and on the left hand into millimetres, but it would be more convenient if this latter scale were divided so as to show the absolute or the back pressure in lbs. per square inch due to an imperfect vacuum. The more perfect the vacuum, the higher the mercury rises in the tube, and every 2 inches of rise corresponds to a diminution of about 1 lb. of back pressure.

It does seem absurd that we should thus continue to register pressures in three or four different ways.

1. In lbs. per square inch above the atmosphere—*e.g.*, in the case of the pressure of steam in a boiler.

2. In inches of mercury from atmospheric pressure downwards, towards a perfect vacuum, or in lbs. per square inch below atmospheric pressure—*e.g.*, in the case of ordinary vacuum gauges.

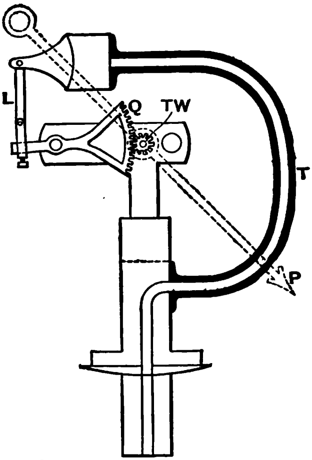
3. In lbs. per square inch reckoned from a perfect vacuum, or what are termed lbs. per square inch absolute—*e.g.*, in the case of the back pressure during exhaust of a condensing engine.

If we universally adopted the last of these methods, there would be no confusion, and only one way of reckoning pressures—viz., from absolute zero. Condenser vacuum pressures would then range from 0 to 15 lbs., and boiler pressures from 15 lbs. upwards.

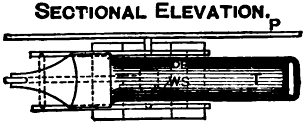
Bourdon's Pressure and Vacuum Gauges.—Steam pressures in boilers or pipes are usually indicated by Bourdon's pressure gauges, and negative or vacuum pressures in condensers, &c., by Bourdon's vacuum gauges, or by instruments of somewhat similar design and construction.

The construction of Bourdon's pressure gauge is clearly shown by the figures on the opposite page. Figure C shows the internal mechanism in its earliest form; the small figure, D, to the right, shows a section of the Bourdon tube; and the upper figures, A and B, show a sectional elevation plan and front view of a modern high-pressure gauge, as made by Schäffer and Budenberg, having a quadrant wheel and pinion arrangement, connecting the pointer, P, with the tube, T. The action of the gauge is as follows (see Fig. A): The steam, gas, or water enters by the cock shown in connection with the gauge to the curved metallic tube, T, of hard brass or steel, whose upper end is hermetically sealed or closed. The cross section of this tube, being of a flat, oval form (with its greatest breadth fixed perpendicularly to the direction in which the tube is curved), tends to become more and more circular in section, the greater the pressure within it (above the atmosphere), and consequently, at the same time, the curve of the tube tends to straighten out, thus pulling the link, L, upwards, the motion of which is transmitted to the quadrant, Q, and thence to the toothed wheel, TW, fixed on the same axis as the pointer, P, which latter moves across the scale.

A



SECTIONAL ELEVATION.



PLAN.

B

FRONT VIEW OF HIGH-PRESSURE GAUGE

C

BACK VIEW OF EARLIEST FORM OF MECHANISM.

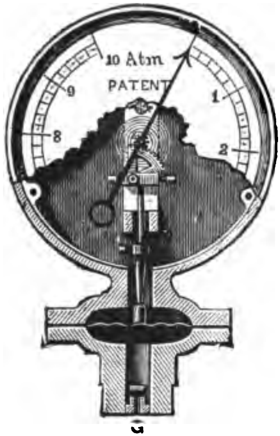
INDEX OF PARTS.

T	represents	Tube,
L	,,	Link.
Q	,,	Quadrant.
TW	,,	Toothed Wheel.
DP	,,	Distance Piece.
P	,,	Pointer.

D

Section of Tube.

Should the pressure within the tube be less than that of the surrounding atmosphere (as is the case when the instrument is measuring the vacuum in a condenser), then the cross-section of the tube becomes flatter than its normal or ordinary shape, and, consequently, the closed end of the tube curves inwards, thus moving the pointer, I, in the other direction.

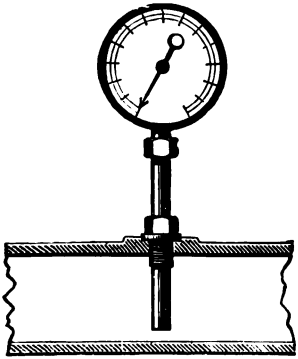


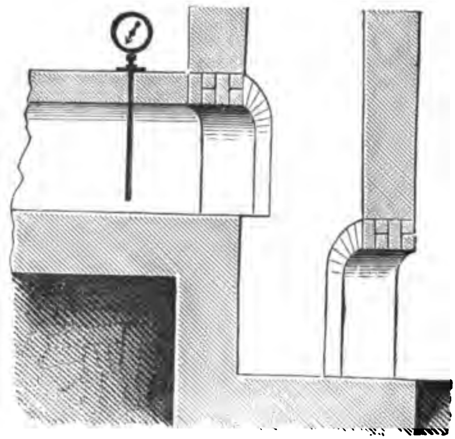
SCHÄFFER'S GAUGE.

It is usual in practice to have separate instruments for recording pressures above and below the atmospheric pressure, and to increase the range of the pointer by the intervention of a toothed lever quadrant fixed between the end of the drag-link and the pointer. This quadrant gears with a small pinnion fixed to the pointer-spindle, and a fine watch-spring, with its inner end attached to this spindle, and its outer end to the case of the instrument, ensures the pointer coming back to zero when the pressure is removed, as well as prevents it lagging behind or sticking. These devices are clearly shown in the above figure, which represents Schäffer's patent, the difference between it and the Bourdon patent being, that the former relies upon the natural elasticity of a concentrically corrugated steel plate placed across the hollow opening in the flange of the pipe, G, which communicates with the boiler or condenser. The centre of this corrugated plate is attached by a clip and rod to the toothed quadrant as shown. When the pressure is greater than that of the atmosphere, the corrugated plate is bulged upwards, and when it is less, it is bulged downwards. These motions, being proportional to the pressures per square inch, are correspondingly indicated on the graduated dial by the pointer.

Pressure Pyrometer.—In Lecture IV., under the heading of Pyrometers, we referred to this instrument, which depends for its action upon the fact that the pressure of a gas, generated from a liquid with which it is in direct communication, corresponds to the temperature of the liquid. The name given to it by the makers is the **Thalpotasimeter**, and it is constructed, as may be seen from the following figures, of a metal stem, containing the liquid, and ending in a Bourdon or Schäffer gauge. The metal stem is shown fixed in the first case into a pipe, and in the second case, into a flue, through which hot gases are passed. Their temperature inside the pipe or the flue is communicated to the stem of the instru-

ment, and therefore to the liquid within it. If water be placed within the stem, then the pressure (and consequently the temperature)





rises in accordance with Regnault's tables (see next Lecture). Instruments filled with ether are made and graduated from 100° to 220° Fah.; those filled with water, from 212° to 680° Fah.; and those filled with mercury, up to 1400° Fah.

LECTURE XI.—QUESTIONS.

1. Describe an experiment for ascertaining approximately the relation between the pressure and temperature of steam at a moderate pressure (say 10 lbs.) above that of the atmosphere. (1887, S. and A. Elemty. Exam.)

2. How would you ascertain the pressure of the vapour of water at a temperature above 212° F.? Describe some method of conducting the experiment.

3. From the table of Regnault's results (Lecture XII.), plot out a curve showing the rise in pressure of steam from 1 lb. to 200 lbs. absolute on the square inch corresponding with increase of temperature. Adopt a scale of 1 inch = 50 lbs. and 1 inch = 100° F.

4. Sketch and describe the mercurial pressure gauge which was much used with low-pressure boilers. Mark on your sketch a scale showing the position of the mercury in the tube with a pressure of 8 lbs. per square inch above atmospheric pressure. Height = 16·3″

5. If the specific gravity of mercury be 13·5, calculate how much higher the mercury will stand in one leg than in the other when the pressure of steam is 10 lbs. on the square inch above the atmosphere. *Ans.* 20·5 inches.

6. Sketch and explain how a barometer gauge is made and fitted to a condenser. If the mercury in an ordinary barometer stands at 30 inches when that in the gauge stands at 26 inches, find the pressure per square inch of the vapour in the condenser. *Ans.* 1·96 lb.

7. Explain what is meant by the expression "a gauge shows 25 inches of vacuum." If the weather barometer stands at 29½ inches, and the condenser gauge at 23 inches, what is the pressure of vapour in the condenser? *Ans.* 3·25 lbs. per square inch.

8. If the vacuum gauge shows 26 inches when the weather barometer shows 30·2 inches, what is the pressure of vapour in the condenser, and what would be the same if the gauge fell to 18½ inches? *Ans.* 2·1 lbs. and 5·85 lbs.

9. What effective pressure is obtained on the piston when the steam gauge shows 25 lbs., and the vacuum gauge 22 inches? *Ans.* 36 lbs. per square inch.

10. What effective pressure is obtained when the steam gauge shows 41 lbs. and the vacuum gauge 27 inches, and what would be the effective pressure if the vacuum fell to 11 inches? *Ans.* 54·5 and 46·5 lbs.

11. Sketch and describe fully by an index of parts (using the first letters of the names of the parts) a Bourdon's pressure and a Bourdon's vacuum gauge. Account for the peculiar action of the tube.

12. Sketch and describe Schäffer's corrugated plate pressure and vacuum gauge.

13. Upon what principle does the pressure pyrometer or thalpotasimeter depend? Sketch such an instrument, and mention for what purposes it is used.

14. Suppose a Bourdon pressure gauge to be faulty in its graduation: sketch how you would connect it up to a mercurial column to test it. If the specific gravity of mercury be 13·5, calculate what every inch of the column will correspond to in lbs. pressure on the square inch. *Ans.* ·49.

15. What do you understand by the statement that there is a vacuum of 10 lbs. registered on the vacuum gauge of a condenser? Sketch and describe fully some form of gauge for testing the pressure in a condenser. (S. and A. Exam., 1894.)

LECTURE XII.

CONTENTS.—Pressure and Volume of a Gas—Boyle's Law—Pressure Volume, and Density—Curve of Volumes and Pressures—Table giving the Chief Properties of Saturated Steam—Watt's Diagram of Work, with Example—Area of Diagram is a Measure of the Work done in One Stroke.

Pressure and Volume.—We saw in Lecture XI., by the experiment with Marcet's boiler, that the pressure of steam increased with the temperature; we now come to consider the relation which exists between *pressure and volume.*

Boyle's Law.—The pressure of a perfect gas *at a constant temperature* varies inversely as the space it occupies.

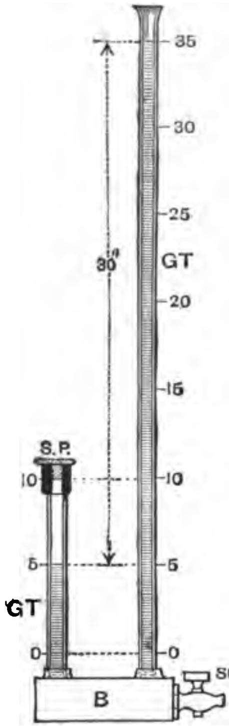
Or, let p = pressure.
v = volume.

Then $p\,v$ = constant, since $p \propto \frac{1}{v}$.

To illustrate this law the following simple piece of apparatus may be used:—

It consists of a small metal box, B, to which are attached two glass tubes, G T, one a little more than 35″ long, and the other fully 10″. A stop-cock, S C, is screwed into the metal box, and the short tube is provided with a screw plug, S P. The whole is fixed to a board, on which there is a graduated scale of inches.

Mercury is poured into the long tube and the screw plug, S P, is taken out until the mercury rises in both tubes to the zero line. The screw plug is then replaced and encloses a column of air 10″ high in the short tube. Supposing the barometer to stand at 30″, we now continue pouring mercury into the long tube until the level of the mercury in it

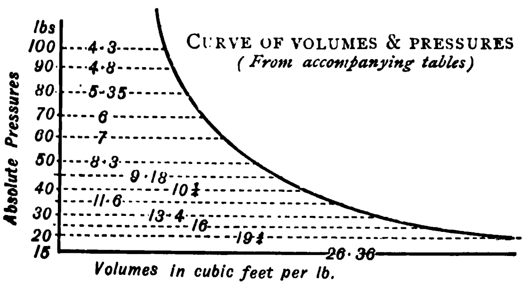


G T for Glass tubes.
B „ Box (air tight).
S C „ Stop-cock.
S P „ Screw plug.

is 30″ *above* the level of the mercury in the short tube. When this point, 35″, is reached, the mercury in the short tube will be found to stand at 5″. The air in the short tube has thus been subjected to an additional pressure of 30″ of mercury, *i.e.*, to an additional pressure of one atmosphere; therefore, its pressure has been doubled. Before applying this pressure it occupied 10″ of the tube; hence we see that its volume has been reduced to one-half by doubling the pressure on it, in accordance with the law just stated. It is important that the student should not overlook the fact, that this law is true, *only* when the temperature remains constant.

This law is not perfectly fulfilled by any actual gas, but very nearly so by those gases which cannot be condensed into liquids, such as air. When a gas is about to pass by condensation into a liquid (*e.g.*, steam on the point of being transformed into water), then the density increases more rapidly than the pressure.

The following curve of "*Volumes and Pressures*" is drawn from the data given in columns 1 and 5 in the Table on the next page. It is plotted in precisely the same way as the curve for "Pressures and Temperatures" explained in last Lecture. It illustrates graphically how the volume of saturated steam diminishes as the pressure rises.



EXPLANATION OF FOLLOWING TABLE, GIVING THE CHIEF PROPERTIES OF SATURATED STEAM.

1st *Column*—gives the Absolute Pressures, or total pressures per square inch, reckoned from a perfect vacuum as zero.

2nd *Column*—gives the temperature at which steam is given off under the corresponding pressures in the 1st column.

3rd *Column*—gives the sum of the Sensible and Latent Heats which Watt believed to be a constant quantity; but which Regnault showed by experiment increases with the temperature (see Lecture IX.). Formula, Total Heat or H = 1082·4 + ·305 *t*°.

4th *Column*—gives the Latent Heat which gets less at higher pressures.

5th *Column*—gives the Specific Volume of steam or *the Volume per pound weight of steam.*

6th *Column*—gives the Density or weight of a cubic foot of steam.

7th *Column*—gives the volume of steam generated under a given pressure compared with the volume of the water from which it is produced.

Properties of Saturated Steam.

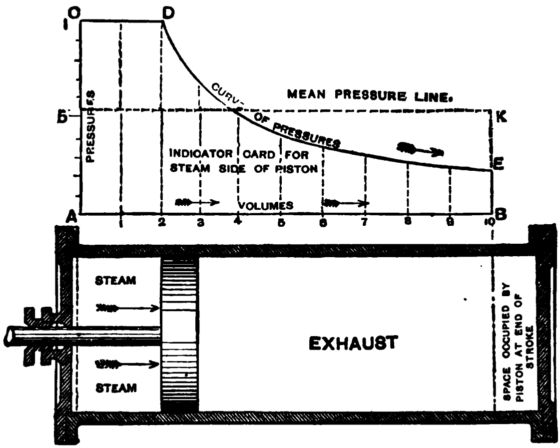
From the Experiments of Regnault and Others.

Absolute Pressures.	Boiling Point of Water and Temperature of Steam.	Total Heat from Water at 32° or Sensible and Latent Heats together.	Latent Heat.	Specific Volume or Volume of 1 lb. of Steam.	Density or Weight of 1 Cubic Foot.	Relative Volume or Cubic Feet of Steam from 1 Cubic Foot of Water.
1.	2.	3.	4.	5.	6.	7.
Lbs. per sq. inch.	Fah.	Units of heat per lb.	Units of heat per lb.	Cubic feet.	Lbs.	Cubic feet.
1	102·1	1112·5	1042·9	330·36	·0030	20600
2	126·3	1119·7	1025·8	172·08	·0058	10730
5	162·3	1130·9	1000·3	72·66	·0138	4530
10	193·3	1140·3	978·4	37·84	·0264	2360
Atmos. pres. 14·700	212·0	1146·1	965·2	26·36	·0380	1642
20	228·0	1150·9	952·8	19·72	·0507	1229
25	240·1	1154·6	945·3	15·99	·0625	996
30	250·4	1157·8	937·9	13·46	·0743	838
35	259·3	1160·5	931·6	11·65	·0858	726
40	267·3	1162·9	926·0	10·27	·0974	640
45	274·4	1165·1	920·9	9·18	·1089	572
50	281·0	1167·1	916·3	8·31	·1202	518
60	292·7	1170·7	908·0	7·01	·1425	437
70	302·9	1173·8	900·8	6·07	·1648	378
80	312·0	1176·5	894·3	5·35	·1869	333
90	320·2	1179·1	888·5	4·79	·2089	298
100	327·9	1181·4	883·1	4·33	·2307	270
110	334·6	1183·5	878·3	3·97	·2521	247
120	341·1	1185·4	873·7	3·65	·2738	227
130	347·2	1187·3	869·4	3·38	·2955	211
140	352·9	1189·0	865·4	3·16	·3162	197
150	358·3	1190·7	861·5	2·96	·3377	184
160	363·4	1192·2	857·9	2·79	·3590	174
170	368·2	1193·7	854·5	2·63	·3798	164
180	372·9	1195·1	851·3	2·49	·4009	155
190	377·5	1196·5	848·0	2·37	·4222	148
200	381·7	1197·8	845·0	2·26	·4431	141
210	386·0	1199·1	841·9	2·16	·4634	135
220	389·9	1200·3	839·2	2·06	·4842	129
230	393·8	1201·5	836·4	1·98	·5052	123
240	397·5	1202·6	833·8	1·90	·5248	119
250	401·1	1203·7	831·2	1·83	·5464	114

Watt's Diagram of Work.—Watt assumed that Boyle's law held good in the case of steam, and he applied it in a most ingenious manner to prove that he could get a greater amount of work out of his engine per pound of steam used, by cutting it off early from the cylinder (and thus allowing it to force the piston forward during the remainder of the stroke, merely by expansion), than by supplying steam throughout the whole stroke, which had been the practice of other engineers.

Although steam, being an imperfect gas, does not expand in strict accordance with Boyle's law, and further, since the temperature of the steam falls the more it is expanded (unless external heat is applied to it, to make up for the loss due to the work got out of it), yet we shall gain a great insight into the action of steam in an engine cylinder, by first discussing "Watt's Diagram of Work done during Expansion."

The following figure illustrates the method adopted by Watt. The horizontal line, or abscissa, AB, indicates the length of the stroke, and is divided into 10 equal parts,* the vertical line, or



WATT'S DIAGRAM OF WORK.

ordinate, AC, represents the pressure of steam used by Watt, about 15 lbs. absolute, or one atmosphere, and it is also divided into 10 equal parts. When the piston has travelled the distance,

* Watt, in his patent of 1782, describes how he divided the length of his cylinder, or stroke of piston, into 20 equal parts; but we have here divided ours only into 10 equal parts, in order to render the figure and the explanation of his method easier to junior students. For similar reasons we have shown the steam cut off at $\frac{1}{5}$ of the stroke, instead of $\frac{1}{4}$ as in his case.

CD, *i.e.*, $\frac{2}{10}$ or $\frac{1}{5}$ of the stroke, the steam is cut off from the cylinder by the steam valve or the slide valve, and the remainder of the stroke is effected solely by the expansive action of the steam. The gradually falling curve, DE, marked "curve of pressures," is found by drawing verticals from each of the divisions of the stroke, 3, 4, ... 10, and marking them off in height corresponding to the pressures, p, at these points, by the formula of Boyle's law, and joining their upper ends by a curved line:—

$$p\,v = \text{a constant, or } p = \frac{\text{constant}}{v},$$

where v = the volume swept out by the piston from the commencement of the stroke, and is, therefore, represented by the different distances, A to 2, to 3, . . . to 10, along the line, AB.

For example—

							Atmosphere.
	At point A, p		. . . . .				1
At point of cut-off	„ 1, p		. . . . .				1
$p = 1$	„ 2, p		. . . . .				1
$v = 2$	„ 3, p	=	$\frac{\text{constant}}{v}$	=	$\frac{2}{3}$	=	0·66
∴ Constant $= p\,v$	„ 4, p	=	„	=	$\frac{2}{4}$	=	0·5
„ $= 1 \times 2$	„ 5, p	=	„	=	$\frac{2}{5}$	=	0·4
„ $= 2$	„ 6, p	=	„	=	$\frac{2}{6}$	=	0·33
	„ 7, p	=	„	=	$\frac{2}{7}$	=	0·29
	„ 8, p	=	„	=	$\frac{2}{8}$	=	0·25
Near end of Stroke,	„ 9, p	=	„	=	$\frac{2}{9}$	=	0·22
	Dividing by the Number of Parts, viz.,					10	) 5·65
	We get roughly a Mean Pressure					=	·565

By adding the several pressures, and dividing them by the number of divisions taken—viz., 10—we get the average pressure throughout the stroke = ·565 of an atmosphere (*i.e.*, ·565 × 14·7 lbs. = 8·3 lbs. per square inch), or more than half the initial pressure. The economy of cutting off the steam before the end of the stroke will, therefore, be at once apparent, for we have obtained an average pressure greater than *half that which would have been obtained by carrying full steam pressure throughout the whole stroke, and have only used* $\frac{1}{5}$ *of the quantity of steam.*

Area of Diagram is a Measure of Work done.—Since work done is measured by force or pressure, multiplied by the distance through which the force or pressure acts, the area of the rectangle, AD (see upper part of last fig.), being equal to the pressure, AC, if reckoned in lbs., multiplied by the distance, A2, or, CD in feet, measures to scale the work done upon the piston by the steam up to the point of cut-off in foot-pounds or units of work. In the same way, the area of the rest of the figure—viz.,

DEB2, measures to scale the work done upon the piston by the steam while expanding in the cylinder, also in foot-pounds; for this area is equal to the mean pressure in lbs. between the points, D and E, multiplied by the distance, 2B, in feet. *Consequently, the area of the whole figure,* ACDEB, *measures to scale the whole work done by the steam in one stroke in foot-pounds.* This area is equal to the calculated mean pressure throughout the stroke, 8·3 lbs., multiplied by the whole stroke, AB in feet, and expresses the results of Watt's diagram of work in foot-pounds. Watt, in calculating the mean pressure throughout the stroke, assumed that the pressure at each of the points into which he divided the stroke remained constant until it arrived at the next in order, by which method he obtained a slightly different value from the true mean pressure. His method is, however, sufficiently accurate for our purposes at the present stage of the student's knowledge.

Methods of Constructing the Curve of Pressures and Volumes by Boyle's Law.—We shall now show how to construct the curve for the relation between pressure and volume of a perfect gas expanding according to Boyle's law. This curve may be constructed in two different ways :—

1. By making use of the formula expressing Boyle's law—viz., pv = a constant, and thus calculating the pressure at various points during the expansion.

2. Or, we may adopt a purely graphical method for determining a series of points on the curve. The *curve of expansion* can then be drawn freehand or by aid of French curves, or by bending a thin flexible strip of wood until its lower edge passes through the several points. These two methods will be clearly understood from the solution of the following example.

EXAMPLE I.—Steam is admitted into the cylinder of an engine at a pressure of 30 lbs. by gauge, and is cut off at $\frac{1}{8}$ of the stroke. Draw to scale the diagram of work done during admission and expansion, assuming that the steam expands according to Boyle's law. From the diagram thus constructed, find the pressures at $\frac{3}{8}$, $\frac{5}{8}$, and $\frac{7}{8}$ of the stroke respectively.

ANSWER.—**First Method, by Calculation.**

Draw two axes O P, O V, at right angles to each other. Along O P, measure off a distance O A, to represent the initial absolute pressure of the steam.*

* The initial pressure as given by the question is 30 lbs. by gauge. The pressure as indicated by a steam gauge on a boiler or cylinder of an engine, has for its starting (or zero) point, the pressure of the atmosphere—viz., about 15 lbs. per square inch. We cannot, therefore, base our calculations respecting a law of nature on such an arbitrary and variable starting-point as this. Consequently, we must refer all our pressures to the *absolute zero* or perfect vacuum line before applying Boyle's law. The absolute zero is

Along O V, measure off a distance O B, to represent the volume of the stroke.*

Divide O B into any number of parts, equal or unequal in length, and at each point of division raise a perpendicular line of indefinite length. In the figure we have divided the

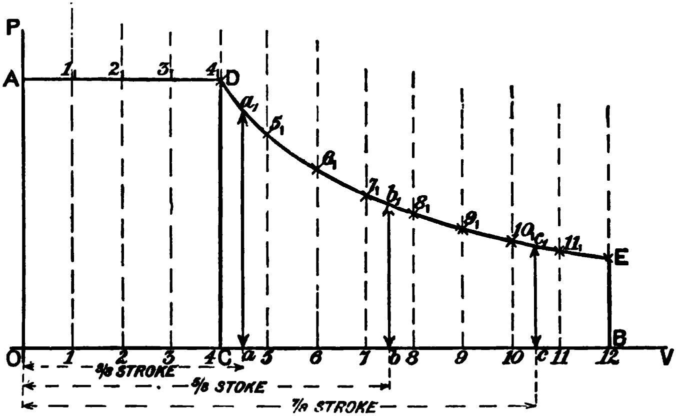


DIAGRAM OF WORK FOR EXAMPLE I.

stroke into 12 *equal* parts, for the following reasons: (1) the number 12 is a multiple of the denominator of the fraction $\frac{1}{3}$ (the fraction of the stroke at cut-off), so that one of the points of division may coincide with the point representing the cut-off; (2) the number of points on the curve will thus be sufficiently numerous or close together to enable us to draw a fairly accurate curve through them; and (3) we have taken the parts of equal length because the stroke will be divided into convenient and easily recognised fractions. We might have divided the stroke into *nine* or even *ten* equal parts, as is usually the case in practice, but, due to the reasons just assigned, we prefer the larger number for the present case.

Denote the pressures and volumes at the points ·0, 1, 2, 3 . . . . 12, by the letters p_0, v_0; p_1, v_1; p_2, v_2; . . . . p_{12}, v_{12}; respectively.

thus about 15 lbs. (more correctly 14·7 lbs.) per square inch below atmospheric pressure. Hence, the initial absolute pressure of steam = 30 + 15 = 45 lbs. per square inch. We have, therefore, to make O A represent this total pressure.

* Since the cross area of the cylinder is constant throughout the stroke, the line O B will also represent to scale the full stroke of the piston, and the distances, O1, O2, O3, &c., definiteproportions of the stroke.

Further, let the whole volume of the piston's stroke be denoted by the number 12—*i.e.*, let $v_{12} = 12$. Then, $v_1 = 1$, $v_2 = 2$, and so on. The utility of this notation will be apparent from the following.

The point of cut off coincides with the point 4 ($\frac{1}{3} \times 12 = 4$), as shown by the figure. Now we know that

$$p_4 = p_0 = 45 \text{ lbs. absolute, and that } v_4 = 4,$$
$$\therefore \text{ by } \textit{Boyle's Law}, \ pv = \text{a constant}$$
$$\therefore \quad \text{The Constant} = p_4\, v_4 = 45 \times 4 = 180.$$

Calculate and tabulate the pressures at the various points during expansion, thus—

$$p_5 = \frac{const.}{v_5} = \frac{180}{5} = 36{\cdot}00 \text{ lbs. abs.}$$
$$p_6 = \frac{const.}{v_6} = \frac{180}{6} = 30{\cdot}00 \quad \text{,,} \quad \text{,,}$$
$$p_7 = \frac{const.}{v_7} = \frac{180}{7} = 25{\cdot}71 \quad \text{,,} \quad \text{,,}$$
$$p_8 = \frac{const.}{v_8} = \frac{180}{8} = 22{\cdot}50 \quad \text{,,} \quad \text{,,}$$
$$p_9 = \frac{const.}{v_9} = \frac{180}{9} = 20{\cdot}00 \quad \text{,,} \quad \text{,,}$$
$$p_{10} = \frac{const.}{v_{10}} = \frac{180}{10} = 18{\cdot}00 \quad \text{,,} \quad \text{,,}$$
$$p_{11} = \frac{const.}{v_{11}} = \frac{180}{11} = 16{\cdot}36 \quad \text{,,} \quad \text{,,}$$
$$p_{12} = \frac{const.}{v_{12}} = \frac{180}{12} = 15{\cdot}00 \quad \text{,,} \quad \text{,,}$$

We now possess all the data for completing the diagram. Along the perpendiculars drawn through the points 4, 5, 6 . . . . 12, measure off distances 4, 4_1, 5, 5_1, 6, 6_1 . . . . 12, 12_1 respectively, to represent (according to the scale previously employed for the pressure O A) the pressures p_4, p_5 . . . . p_{12}, given above. Then 4_1, 5_1 6_1 . . . . 12_1, are points on the expansion curve. Join A with point 4_1, and through the points 4_1, 5_1, 6_1 . . . . 12_1, draw carefully by hand (or otherwise as previously directed) an unbroken continuous curve, D E. This is the expansion curve, and is known to mathematicians as a *Rectangular Hyperbola*. The area of the rectangle O A D C represents the work done to the point of cut off; the area of the figure C D E B represents the work done during expansion. The area

of the whole figure O A D E B represents to scale the complete diagram of work.

We are also asked by the question to find, from the diagram thus constructed, the pressures at $\frac{3}{8}$, $\frac{5}{8}$ and $\frac{7}{8}$ of the stroke.

Since the length of stroke has been denoted by the number 12, we, therefore, get—

$$\begin{aligned} \tfrac{3}{8} \text{ stroke} &= \tfrac{3}{8} \times 12 = 4{\cdot}5 \\ \tfrac{5}{8} \quad \text{,,} \quad &= \tfrac{5}{8} \times 12 = 7{\cdot}5 \\ \tfrac{7}{8} \quad \text{,,} \quad &= \tfrac{7}{8} \times 12 = 10{\cdot}5 \end{aligned}$$

These points are easily found, and are indicated on the right-hand part of the figure by the letters *a*, *b*, and *c* respectively. Drawing the *ordinates*, aa_1, bb_1, cc_1, and measuring their lengths, we get, according to the scale of pressures, the following results—

$$\begin{aligned} aa_1 &= 40{\cdot}00 \text{ lbs. abs.} \\ bb_1 &= 25{\cdot}00 \quad \text{,,} \\ cc_1 &= 17{\cdot}14 \quad \text{,,}^* \end{aligned}$$

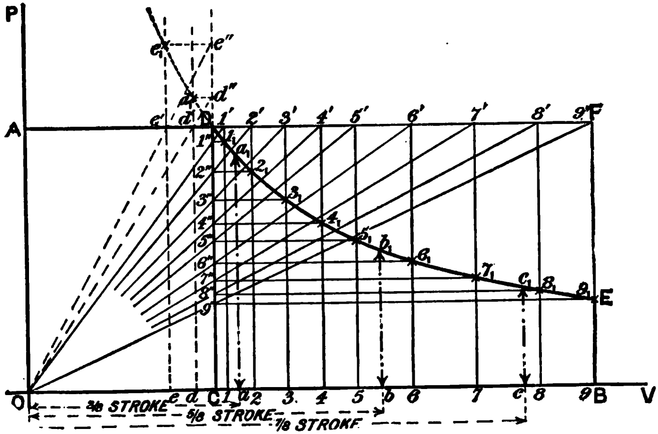
Second Method: by Graphical Construction.—As before, draw two axes O P, O V, and measure off the distances O A, O B, to represent the initial pressure and the volume of stroke respectively. Let O C represent the volume swept through by the piston to the point of cut off. Complete the rectangles O A D C, O A F B. Divide C B into any number of equal or unequal parts, and at these several points of division raise perpendiculars to meet the line A F.†

To find points on the expansion curve, join the origin O, with the point 1′, on the line A F. This line cuts the perpendicular C D, in the point 1″. Through point 1″, draw the line 1″ 1_1, parallel to O V, and terminated by the perpendicular through point 1. *The point* 1_1, *is a point on the expansion curve.* Similarly, join O 2′. This line O 2′, cuts the perpendicular C D in the point 2″. Through 2″, draw the line 2″2_1, parallel to O V, to meet the perpendicular 2, 2′, in point 2_1. *Then, point* 2_1, *is also a point on the expansion curve.* By proceeding in this way, as shown by the figure, we get the series of points 1_1, 2_1, 3_1 . . . .

* These are the exact values, as may be readily proved by calculation. When, however, the measurements are carefully made, and the curve neatly drawn, such results should not differ from the correct results by more than 2 or 3 per cent.

† An inspection of the curve D E (in the previous figure) shows that it is steeper near to the end D than it is towards the end E. Hence, if we use equidistant ordinates, a greater length of curve will lie between two consecutive points near the end D than towards the flatter portion of the curve at E. For this reason, it is advisable to have the points 1, 2, 3 . . . near to C, much closer together than those points towards the end B.

on the curve. The curve can then be drawn through the points thus found.



GRAPHIC CONSTRUCTION FOR FINDING POINTS ON EXPANSION CURVE.

The pressures at $\frac{3}{8}$, $\frac{5}{8}$, and $\frac{7}{8}$ of the stroke can then be found as before, by measuring the ordinates through the points *a*, *b*, and *c* respectively.

If the steam was *compressed*, according to Boyle's law, from an initial volume O C, the curve of compression would be a continuation of the curve E D, as shown in dotted line by the figure. The method of drawing the compression curve is identically the same as that described above for the expansion curve. It will be sufficient to show how to find one point on this compression curve.

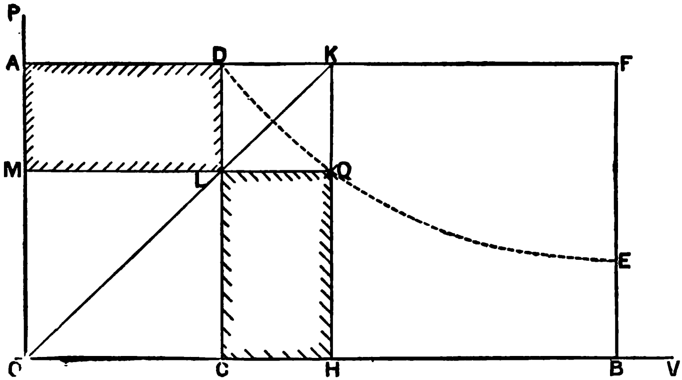
Suppose we require to find the pressure when the volume is diminished to O *d*. Through *d*, draw the perpendicular dd_1 cutting A F, in the point d'. Join O d', and produce it to meet C D, produced in d''. Through d'', draw $d''d_1$, to meet $d\,d_1$, in d_1. *Then* d_1 *is a point on the compression curve.*

Proof of above Construction.—That the above construction is mathematically correct may be proved as follows:

Let O A = Initial pressure, p_c,
O B = Volume of stroke,
O C = Volume to cut off, v_c.

Let the pressure and corresponding volume at any other point H

of the stroke be represented by the letters p_h and v_h respectively. Complete the rectangles O A D C, O A F B. Find by the previous construction the point Q, on the expansion curve corresponding



ILLUSTRATING PROOF FOR GEOMETRICAL CONSTRUCTION.

to volume O H. Produce Q L to meet O P in M. Then the area of the rectangle O A D C represents the product, $p_c\ v_c$, *i.e.*, the pressure × the volume at the point C. We have now to prove that—*area of rectangle* O M Q H = *area of rectangle* O A D C.

Since O A K H, is a parallelogram having parallelograms, O M L C, L D K Q, described on its diagonal O K, then the remaining parallelograms M A D L, and C L Q H (which make up the complete figure O A K H) are called *complementary parallelograms*. Now, by *Euclid, Book I. proposition* 43, it is proved that the areas of complementary parallelograms are equal. Hence the parallelogram C L Q H = the parallelogram M A D L. Add to each side of this equation the parallelogram O M L C, and we get—

$$Area\ O\ M\ Q\ H = Area\ O\ A\ D\ C$$
$$i.e.\ \mathrm{H\ Q \times O\ H = O\ A \times O\ C}$$
$$\text{Or,}\quad p_h \times v_h = p_c \times v_c$$

Which proves that Q is a point on the expansion curve.

Simpler Proof.—The following is a still simpler proof. In the similar triangles O L C, and O K H, we get—

$$\mathrm{C\ L : C\ O = H\ K : H\ O} \quad \text{(Euclid VI.–2.)}$$
$$\therefore \mathrm{C\ L \times H\ O = H\ K \times C\ O}$$
$$\text{But, } \mathrm{C\ L = H\ Q, \text{ and } H\ K = O\ A}$$
$$\therefore \mathrm{H\ Q \times H\ O = O\ A \times O\ C}$$
$$\therefore \text{As before } p_h \times v_h = p_c \times v_c$$

LECTURE XII.—QUESTIONS.

1. State Boyle's law, and describe an experiment to show that the pressure of a gas varies inversely as the space it occupies.

2. Referring to Regnault's table in this Lecture, draw a curve of volumes and corresponding pressures from 10 to 50 lbs. absolute, taking ·1 inch to represent the volume of 1 lb. of steam, and also 1 lb. of pressure per square inch.

3. Steam is admitted into a cylinder at atmospheric pressure, and is cut off at half stroke. Divide the stroke into 10 equal parts, and, supposing that the pressure at the beginning of each of these portions remains uniform until the piston reaches the next in order, find the pressure at each point as well as the mean pressure by Watt's method. *Ans.* ·83.

4. A certain quantity of steam at 40 lbs. pressure absolute is admitted into a cylinder, and then expands to 4 times its original bulk. What is its final pressure? Explain what is meant by steam of 40 lbs. absolute. *Ans.* 10 lbs. absolute.

5. The piston of an engine moves through 12 inches under a pressure of 30 lbs. absolute; the steam is then cut off and allowed to expand. What will be its pressure when the piston has moved through 18 inches from the beginning of its stroke? *Ans.* 20 lbs. absolute.

6. Steam is admitted into a cylinder at atmospheric pressure, and is cut off at $\frac{1}{4}$ stroke. Find the pressure when the piston has reached $\frac{11}{16}$ of its full stroke. *Ans.* 4·4 lbs. absolute.

7. Steam of 40 lbs. absolute pressure is admitted into a cylinder. Find the final pressure in each of the following cases:—1st, when it is cut off at $\frac{1}{8}$ stroke; 2nd, when at $\frac{1}{4}$ stroke; 3rd, when at $\frac{1}{2}$ stroke; 4th, when at $\frac{3}{4}$ stroke. *Ans.* 1st = 5 lbs.; 2nd = 10; 3rd = 20; 4th = 30.

8. Steam is admitted into the cylinder of an engine at 9 lbs. above the atmosphere (taken at 15 lbs. per square inch), and is expanded down to 7 lbs. below the atmosphere. Find the pressure of the steam at half-stroke, and the point of cut-off. (S. & A. Exam. 1890.) *Ans.* 1 lb. above the atmosphere, or 16 lbs. absolute; $\frac{1}{3}$ stroke.

9. When is steam said to be be *saturated*? Distinguish between *saturated* steam and *superheated* steam. When air is compressed without change of temperature its pressure is increased according to Boyle's law; state what happens when saturated steam is compressed in like manner without change of temperature? (S. & A. Exam. 1891.)

10. What do you understand by the expansion of air or gas according to Boyle's law? Assuming that steam expands in this way, find the pressure of steam on its admission into a steam cylinder under the following conditions:—Length of stroke of piston is 5 feet, steam is cut off after the piston has described 2 feet, and expands down to 3 lbs. below the atmospheric pressure (taken at 15 lbs.) (S. and A. Exam. 1891.) *Ans.* 30 lbs. absolute.

11. The pressure of steam is 30 lbs. above the atmosphere, and the cut-off takes place when the piston has moved 5 inches. The mean resistance of the load = 18 lbs., and the steam is supposed to expand according to Boyle's law, how much farther will the piston have moved when the actual pressure of the steam just balances the resistance? (S. and A. Exam., 1893.) *Ans.* It may be asked, what is meant by "the mean resistance of the load being 18 lbs?" Does it mean 18 lbs. above atmospheric pressure, or 18 lbs. absolute? Again, what is meant by the expression, "*actual*

pressure of the steam just balances the resistance?" The pressure will be *actual*, no matter what its value may be. Taking the question to read thus: "The mean resistance of the load corresponds to a pressure of 18 lbs. above atmospheric pressure, and the steam is supposed to expand according to Boyle's law, how much farther will the piston have moved when the pressure of the steam just balances the resistance?" *Ans.* 1·82 inches.

12. Assuming, as was done by Watt, that the actual expansion curve of steam is the same as that of air when expanding at a constant temperature, set out an approximate expansion curve when steam of a volume 10 cubic feet, and pressure 65 lbs. per square inch above the atmosphere, is expanded to a volume of 40 cubic feet. (S. and A. Exam., 1894.)

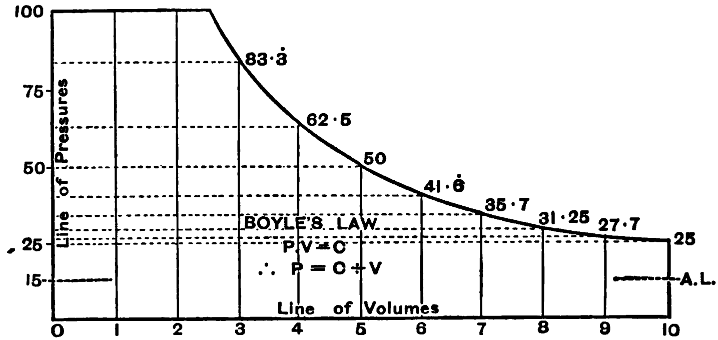
LECTURE XIII.

CONTENTS.—Finding the Mean Pressure from a Theoretical Diagram of Work.

Finding the Mean Pressure.—Let us try another example of Watt's diagram of work. Suppose we have an engine using steam of 100 lbs. pressure absolute per square inch, and cutting off at $\frac{1}{4}$ of the stroke. We find the curve of expansion by Boyle's law and the mean pressure precisely as we did in the last Lecture, with this difference, that we shall add the last pressure ordinate in order to get a nearer approximation to the true mean absolute pressure. In this example, as in the last, we shall assume that there is no back pressure whatever; or, in other words, that a perfect vacuum continues throughout the whole of the exhausting stroke. This, of course, does not take place in actual practice, as we shall learn further on, but our chief object at present is to impress upon junior students the simplest methods of finding the mean pressure and the area of the diagram of work.

There are several rules for obtaining approximately the mean pressure from a diagram of work such as we are now discussing. The plan most commonly adopted by engineers (as we shall see later on) in finding the mean pressure from actual indicator diagrams is, to measure by a suitable scale or rule the length of each of the ten ordinates, taken at the centre of each of the ten spaces into which the diagram is divided, add them together, and divide by their number. For instance, applying this rule to the following figure, we should measure the length of the vertical lines midway between the points 0 and 1, 1 and 2, 2 and 3, ... 9 and 10, add these ten pressure ordinates together, and divide the sum by 10, to get the mean pressure; and doing so (or calculating these pressures by $p\,v$ = constant), we find them to be respectively, 100, 100, 100, 71·43, $55{\cdot}\dot{5}$, $45{\cdot}\dot{4}\dot{5}$, 38·46, $33{\cdot}\dot{3}$, 29·41, and 26·31 lbs., giving a mean of 59·9 lbs., or slightly greater than that found by the calculations on the opposite page.

Economy Due to Cutting Off Early.—EXAMPLE I.—We also see the economy or gain effected by "cutting off" the steam early from the cylinder and doing work during the rest of the stroke by the mere expansive force of the steam; for, the *mean*



As before—	At 0, p	. . . . .			100 lbs.
	At point 1, p	. . . . .			100 ,,
	,, 2, p	. . . . .			100 ,,
	,, 3, p =	$\frac{\text{constant}}{v}$	= $\frac{25}{\cdot 3}$	=	$83\cdot\dot{3}$,,
	,, 4, p =	,,	= $\frac{25}{\cdot 4}$	=	62·5 ,,
Constant $= p\,v$	,, 5, p =	,,	= $\frac{25}{\cdot 5}$	=	50 ,,
,, $= 100 \times \frac{1}{4}$	,, 6, p =	,,	= $\frac{25}{\cdot 6}$	=	$41\cdot\dot{6}$,,
,, $= 25$	,, 7, p =	,,	= $\frac{25}{\cdot 7}$	=	35·7 ,,
	,, 8, p =	,,	= $\frac{25}{\cdot 8}$	=	31·25 ,,
	,, 9, p =	,,	= $\frac{25}{\cdot 9}$	=	$27\cdot\dot{7}$,,
	,, 10, p =	,,	= $\frac{25}{1}$	=	25 ,,
	Dividing by the Number of Points, viz.,			11)	657·2 ,,
	We get an approximate Mean Pressure			=	59·7 ,,

pressure per square inch on the piston is $p = 59\cdot7$ lbs. This is greater than half the initial pressure, 100 lbs., although the steam was cut off from the cylinder when the piston had only moved through $\frac{1}{4}$ of its stroke. Suppose that we consider the stroke of the piston to be, $L = 5$ feet, then,—

The work done in one stroke upon every square inch of the piston's area is equal to the mean forward pressure in lbs. per square inch multiplied by the length of the stroke in feet.

Or, $\quad p \times L =$ Work done per sq. in.

$59\cdot7$ (lbs.) $\times$ 5 (ft.) $=$ 298·5 ft.-lbs.

If we assume the area of the piston to be 100 square inches, then,—

The whole work done in one stroke = Work done upon every square inch multiplied by the area of piston in square inches.

Or—

$$\begin{array}{l} p \times L \times A = \text{Whole work done in one stroke.} \\ 59{\cdot}7\ (\text{lbs.}) \times 5\ (\text{ft.}) \times 100\ (\text{sq. ins.}) = 29{,}850\ \text{ft.-lbs.} \end{array}$$

Had steam of the full initial pressure (P = 100lbs.) been continued throughout the whole stroke, then,—

$$\begin{array}{l} P \times L \times A = \text{Whole work done in one stroke.} \\ 100\ (\text{lbs.}) \times 5\ (\text{ft.}) \times 100\ (\text{sq. ins.}) = 50{,}000\ \text{ft.-lbs.} \end{array}$$

$$\text{But } 50{,}000\ (\text{ft.-lbs.}) : 29{,}850\ (\text{ft.-lbs.}) :: 100 : x.$$
$$x = 59{\cdot}7 \text{ per cent.}$$

In other words, by cutting off at $\frac{1}{4}$ stroke and letting the steam *then* act expansively, we get more than half the work that we would have got from 4 times the weight of steam of the same initial pressure if used non-expansively.

What percentage gain per pound of steam used does this amount to?

For a certain weight of steam (viz., the weight of steam that fills the cylinder at 100 lbs. pressure) we get 50,000 ft.-lbs. of work.

For $\frac{1}{4}$ of this weight of steam used expansively we get 29,850 ft.-lbs. of work.

Therefore, for the same weight as before we would get—

$$29{,}850 \times 4, \text{ or } 119{,}400 \text{ ft.-lbs. of work.}$$

Consequently, for every 1 lb. of steam used non-expansively we have to use—

$$50{,}000\ (\text{ft.-lbs.}) : 119{,}400\ (\text{ft.-lbs.}) :: 1\ (\text{lb. steam}) : y.$$
$$y = 2{\cdot}39 \text{ lbs.}$$

Or, it would take 2·39 lbs. of steam used non-expansively at 100 lbs. pressure to do the same amount of work as 1 lb. used expansively and cut off at $\frac{1}{4}$ stroke with the same initial pressure;

$$i.e.,\ 1 : 2{\cdot}39 :: 100\,\% : z.$$
$$z = 239 \text{ per cent.}$$

$\therefore$ (239 % − 100 %) = 139 per cent. gain by the adoption of cutting off at $\frac{1}{4}$ stroke and taking advantage of the expansive properties of steam.

Advantages arising from Condensing Steam.—The advantages arising from condensing the steam during exhaust are also rendered apparent from this example. For had the exhaust taken place freely against the atmospheric pressure (instead of under

the ideal perfect vacuum that we assumed), the back pressure or exhaust line would have been as high up as the points marked 15 lbs. or A L (for atmospheric line), and the mean pressure per square inch would have been reduced from 59·7 lbs. by 15 lbs., or 25 per cent. less work would have been got per stroke from the engine (see last figure).

EXAMPLE II. (from the Science and Art Elementary Paper on Steam, 1887).—What do you understand by the expansive working of steam? If steam be admitted into the cylinder of an engine at a pressure of 30 lbs. above that of the atmosphere (which is taken at 15 lbs. per square inch), and be cut off at one-third of the stroke, what is its pressure at the end of the stroke?

N.B.—Before answering this question we would again draw the student's attention to the great advantage of *always* underlining the most important words of a question *after* he has read the question over, and carefully considered what is asked or wanted, and *before* he attempts to write down his answer. He should also endeavour to use the examiner's own wording as far as it is given in the question.

Answer.—1. I understand by the expansive working of steam, that process known as "cutting off" the admission of steam from the cylinder of an engine when the piston has been forced through a certain fraction of its stroke (say $\frac{1}{4}$ or $\frac{1}{3}$ or $\frac{1}{2}$), and then completing the stroke by aid of the natural expansive property which steam as well as all gases possesses. By so doing, we obtain more work per pound of steam than if expansion had not taken place.

2. *The pressure of steam admitted into the cylinder is 30 lbs. above that of the atmosphere,* consequently its total pressure is $(30 + 15) = 45$ lbs. *absolute.* By Boyle's law, the pressure multiplied by its volume is a constant.

Or, $\quad p \times v =$ a constant.

In this case the constant is determined from the pressure and the volume at the point of cut-off.

When the steam is cut off, $p = 45$ lbs., and $v = \frac{1}{3}$ of whole volume of cylinder.

Therefore, $\quad 45 \times \frac{1}{3} = 15$ (constant).

At the end of the stroke, $v = 1$,

And, $\quad p = \dfrac{\text{constant}}{v} = \dfrac{15}{1} = \underline{15 \text{ lbs. absolute.}}$

EXAMPLE III.—The cylinder of a condensing engine is 30 inches long (clearance neglected). Steam is admitted at 20 lbs.

absolute; the final pressure is 5 lbs. absolute. At what point of the stroke was the steam cut off?

Answer.—In this case the constant is determined from the pressure and the volume at the end of the stroke, or what amounts to the same thing (as far as the calculation is concerned), viz., the pressure and the full stroke or length of cylinder, for the volume is in direct proportion to the distance moved by piston.

By Boyle's formula—

$$\begin{array}{cccc} p & \times & v & = \text{constant.} \\ 5\text{ (lbs.)} & \times & 2\cdot5\text{ ft.} & = \quad 12\cdot5. \end{array}$$

At the point of cut off, the pressure × the volume must also be equal to 12·5, but the pressure is 20 lbs.

$$\therefore \quad p \times v = 12\cdot5$$

$$20 \times v = 12\cdot5$$

$$v = \frac{12\cdot5}{20} = \cdot625 \text{ feet} = \underline{7\cdot5} \text{ inches.}$$

EXAMPLE IV.—A cylinder of a condensing engine is 4 feet long (clearance neglected). Steam is cut off at $\frac{1}{4}$ stroke, and the final pressure is 10 lbs. absolute. At what pressure was steam admitted?

Answer.—Here again the constant is determined from the final pressure and volume, or stroke.

By Boyle's formula—

$$\begin{array}{cccc} p & \times & v & = \text{constant.} \\ 10\text{ (lbs.)} & \times & 4\text{ (ft.)} & = \quad 40. \end{array}$$

At the point of cut-off, the volume is represented by $\frac{1}{4}$ of the stroke, or $\frac{1}{4}$ of 4 feet = 1 foot.

$$\therefore \; p \times v = \text{constant (above).}$$

$$p \times 1 = 40.$$

$$\therefore \qquad p = \underline{40} \text{ lbs. absolute.}$$

The pressure at the point of cut-off being 40 lbs., the pressure at which the steam was admitted must also be 40 lbs., since we at present do not recognize wire-drawing, &c., or any circumstance causing a fall of pressure between admission and cut-off.*

* For a method of finding the mean pressure and the work done during expansion, see Lecture XVI. of the Author's "Text-Book on Steam and Steam Engines."

LECTURE XIII.—QUESTIONS. *

1. Given the initial pressure 50 lbs. by gauge, length of stroke 5 feet, cut off at 1 foot. Find the pressure at every foot of the stroke, and then the average or mean pressure. Assume exhaust to take place at a perfect vacuum, or 0 lb. pressure, and that the atmospheric pressure is 15 lbs. *Ans.* 35·5 lbs. mean pressure.

2. The initial pressure of steam is 45 lbs. above that of the atmosphere, and the atmospheric pressure is 15 lbs. per square inch; the steam expands five times. What is the final pressure? Set off the expansion curve in a diagram, and mark the position of the atmospheric line. (S. and A. 1888 Elementary Examination.) *Ans.* 12 lbs. absolute.

3. The cylinder of an engine is 25 inches long, and steam is admitted at 18 lbs. absolute pressure, the final pressure being 4 lbs. absolute. At what point of the stroke was the steam cut off? *Ans.* $5\cdot\dot{5}$ inches.

4. Steam is admitted into a cylinder at a pressure of 25 lbs. on the square inch above the atmospheric pressure of 15 lbs. on the square inch, and is cut off at such a point that its pressure at the end of the stroke is 5 lbs below that of the atmosphere. At what point of stroke was it cut off? Make a diagram, showing approximately the steam pressure on the piston throughout the stroke. *Ans.* Cut off at ·25 or ¼ stroke.

5. The cylinder of an engine is 25 inches long; steam is admitted at 18 lbs. absolute, and the final pressure is 4 lbs. absolute. Divide the stroke into 10 equal parts; find the steam pressure at each point of division, and set out Watt's diagram of work done. Find also the mean pressure of the steam. *Ans.* 18, 18, 13·5, 10, 8, $6\cdot\dot{3}$, 5·7, 5, $4\cdot\dot{4}$, 4. Mean pressure = 10 lbs.

6. The stroke of a piston is 4 feet 6 inches, the steam is cut off at 9 inches, and the pressure at the end of the stroke is 5 lbs. below that of the atmosphere. At what pressure above the atmosphere was steam let in? *Ans.* 45 lbs.

7. Steam is admitted into the cylinder of an engine at an absolute pressure of 45 lbs. per square inch, and is cut off at one-third of the stroke. Find the pressure in lbs. at half-stroke, and also at the end of the stroke. Show roughly, by a diagram, that additional work is obtained from a given quantity of steam—(1) by cutting off the supply from the boiler before the end of the stroke; (2) by condensing the steam instead of allowing it to escape into the air. *Ans.* 30 lbs.; 15 lbs.

8. Explain the advantage of working steam expansively, and with condensation. Steam is admitted into a cylinder at 30 lbs. above the atmosphere, which is taken at 15 lbs. per square inch, and is cut off at a certain point, and then expands to a pressure of 5 lbs below the atmosphere. If the length of stroke be 4½ feet, at what point is the steam cut off? *Ans.* At ⅕, or ·2 of stroke.

9. Steam expands in the cylinder of an engine from a pressure of 30 lbs. above the atmosphere to 5 lbs. below the atmosphere, at what part of the stroke was the steam cut off? The pressure of the atmosphere may be taken at 15 lbs. (S. and A. Exam., 1889.) *Ans.* ·2 of stroke.

10. Sketch the diagram of work as applied by Watt to explain the advantage of expanding steam in the cylinder of an engine. Steam enters the cylinder at 60 lbs. pressure (absolute), and is cut off at ¼th of the stroke. Find pressure at ¼, ½, ¾, and end of stroke. (S. & A. Exam., 1892.) *Ans.* 48 lbs.; 24 lbs.; 16 lbs.; 12 lbs.

* See Appendix for more recent S. & A. Questions.

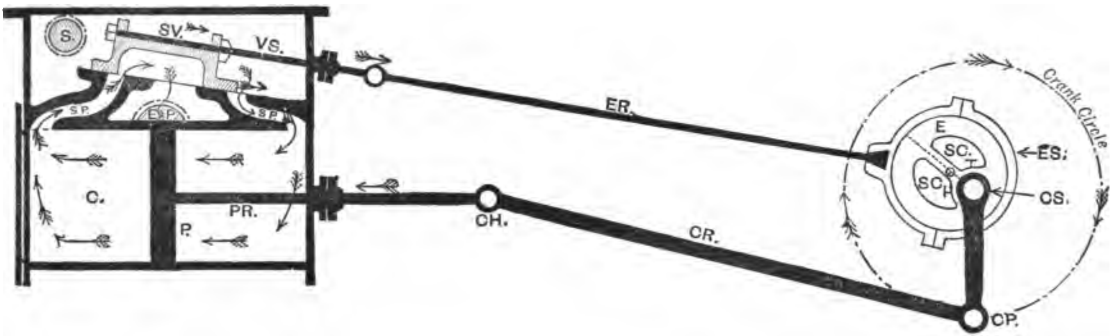
LECTURE XIV.

CONTENTS.—General Idea of the Relative Positions and Motions of the Chief Parts of a Steam Engine—Relative Positions of the Crank and Piston—Relative Positions of the Eccentric and the Slide Valve—Eccentric Pulley and Strap—Wilkinson's Valvometer.

General Idea of the Relative Positions and Motions of the Chief Parts of a Steam Engine.—Before explaining the Indicator and the results obtained by it in the form of Indicator Diagrams, it will be necessary to describe the relative positions and motions of the piston, connecting rod, and crank, as well as that of the eccentric, eccentric rod, and slide valve, in order to understand the distribution of steam in the cylinder of an ordinary engine.

This is most graphically and easily done in the case of a class by the aid of a large skeleton working model (placed on the lecture-table and demonstrated by the teacher), in which the several moving parts are all in one plane, so that their relative positions and motions may be simultaneously observed and sketched. Students should be encouraged to make a small skeleton working model to scale in stiff cardboard or in sheet-brass, and to draw from it sketches in their exercise-books, showing the exact positions of all the parts when steam is admitted to, cut off from, released from, exhausting from, and compressed in the cylinder. By so doing, they will obtain and retain a much more exact and definite conception of the action of a steam engine, than can possibly be given to them by any number of diagrams from a book or drawings on a black-board.

The following figure represents a section of such a model. It will be observed that the to-and-fro or reciprocating movement of the piston, P, in the cylinder, C, is converted by aid of the piston rod, P R, and connecting rod, C R, into the right-hand circular motion of the crank pin, C P, as indicated by the "*crank-pin circle,*" whereas, the to-and-fro or reciprocating motion of the slide valve, S V, is obtained or derived from the circular motion of the centre of the eccentric (sheave or pulley), E, by aid of the eccentric strap, E S, eccentric rod, E R, and valve spindle, V S,

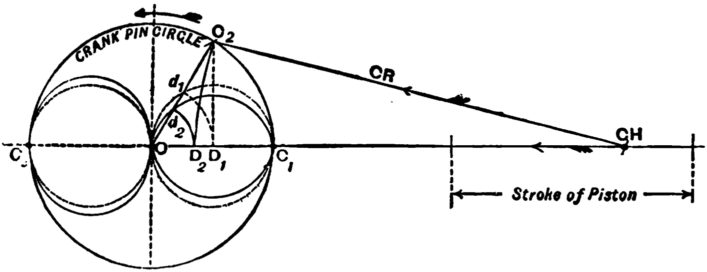


INDEX TO PARTS.

C for Cylinder.	CP for Crank pin.	SV for Slide valve.	SC for Set screws for adjusting eccentric to any angle with respect to the crank.
P ,, Piston.	CS ,, Crank shaft.	VS ,, Valve spindle.	
PR ,, Piston rod.	S ,, Steam pipe.	ER ,, Eccentric rod.	
CH ,, Crosshead.	SP ,, Steam ports.	E ,, Eccentric (pulley).	
CR ,, Connecting rod.	EP ,, Exhaust ports.	ES ,, Eccentric strap.	

The above diagram represents a working model belonging to The Glasgow and West of Scotland Technical College, about 10 feet long, with a cylinder 18 inches diameter and 24 inches stroke, presented by David Rowan, Esq., M. Inst. C.E., and fitted in the college workshop by one of the students, with a separate set of link motion, double eccentrics, &c., not shown in this figure, which can be put on and adjusted in a few minutes.

The crank and the eccentric pulley are rigidly fixed or keyed to the crank shaft, C S, in definite positions or at a definite angle with respect to each other, so that the relative positions of the slide valve and the piston with which they are respectively in circuit may produce the required result of permitting the steam to enter and leave the cylinder at the proper times. The slide valve having to be always ahead or in front of the piston's motion, the eccentric must of necessity be fixed ahead of the crank by a definite angle.



Relative Positions of the Crank and the Piston.—The following method of determining the relative positions of the crank and the piston is of great importance. It is also the method used in determining the relative positions of the eccentric and its slide valve.

In the fig., let OC_2 represent the crank, then with centre, C_2, and radius (CR) = the connecting rod, describe an arc cutting the centre line of the engine's stroke in (CH), which gives the position of the crosshead. With this point (CH) as a centre, and the length of (CR) as radius, describe the arc, C_2D_2. The length OD_2 will be equal to the distance of the piston from the *middle* of its stroke when the crank is in the position OC_2. If this distance, OD_2, be set off along the crank, OC_2, by drawing with centre, O, and radius, OD_2, the arc, D_2d_2, and the same operation be repeated for a series of different positions of the crank, all these points will be found to lie on the polar curve, Od_2C_1. Any chord of this curve drawn from the point O will be equal to the distance of the piston from the middle of its stroke when the crank lies along that chord.

The double looped curves in *full* lines are the curves obtained by this method.

If the connecting rod be infinitely long, it is evident that instead of the arc, C_2D_2, we get the straight line, C_2D_1, at right angles to the line of stroke, and that OD_1 is, in this case, the distance of

the piston from the middle of its stroke. If this distance be set off along the crank by drawing the arc, D_1d_1, and the same operation be repeated for a series of different positions of the crank, it will be found that all these points lie on a pair of circles drawn with OC_1 and OC_2 as diameters. These are shown by the dotted circles in the figure.

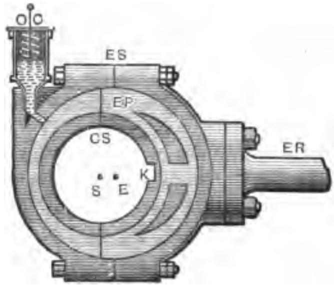
The effect of the obliquity of the connecting rod is well seen by comparing the curves in full lines with the circles in dotted lines.

In valve diagrams it is usual to neglect the effect of the obliquity of the eccentric rod, because the ratio of its length to the throw of the eccentric is generally great, and its effect is therefore generally not worth taking into account.

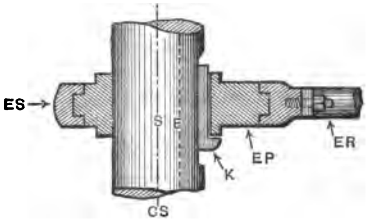
When the piston is at the commencement of its stroke, the crank is in the position, OC_1, and when the piston is at the end of its stroke, the crank is in the position, OC_2. In each of these positions, the connecting rod is in the same plane as the line of the crank; consequently the pressure of the steam on the piston produces simply a direct thrust on the bearings, without causing any tendency to turn the crank shaft. Hence these two positions are termed the "*dead points*" or "*dead centres*," from the fact that a single cylinder engine cannot be started when the crank is on either dead centre.

Twice in every revolution the centre line of the connecting rod is brought at right angles to the crank, or, in other words, it forms a tangent to the crank-pin circle. At these two positions, the force transmitted through the connecting rod acts with the greatest turning effect, because the leverage is greatest at these points, and the thrust due to this force through the crank on the crank-shaft bearing is nil. The longer the connecting rod, the nearer will the crank then be at right angles to the centre line of the piston's motion, or to the line C_1C_2, the line of "dead centres," in the last figure, and if the connecting rod were infinitely long, it would be exactly at right angles to C_1C_2.

Relative Positions of the Eccentric and the Slide Valve.—The "eccentric" is simply a particular form of crank, in which the crank pin is large enough to embrace the crank shaft, the part which corresponds to the crank pin being the eccentric sheave or pulley. The crank has this advantage over the eccentric, that it can be employed for converting reciprocating into circular motion or the reverse, whereas the eccentric (owing to the greater leverage at which the friction between its pulley and strap acts, compared with its turning leverage) can only be used for converting circular into reciprocating motion. Eccentrics are, however, applicable where ordinary cranks are inadmissible, from the fact that the shaft does not require to be divided where an eccentric is applied.



Side Elevation.



Sectional Plan

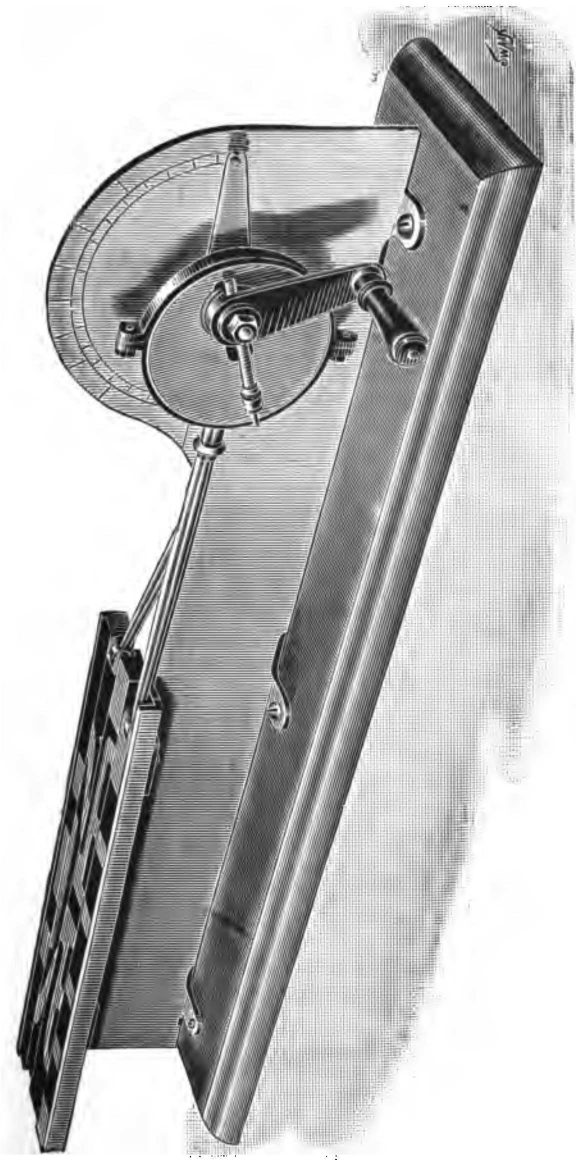
ECCENTRIC FOR HORIZONTAL ENGINE:

INDEX TO PARTS.

C S for Crank shaft.		E	for Eccentric centre.
E P	,, Eccentric pulley.	K	,, Key to fix E P to C S.
E S	,, Eccentric strap.	O C	,, Oil cup.
S	,, Shaft centre.	E R	,, Eccentric rod.

The above figure shows an eccentric pulley and strap for a horizontal engine, with the way in which it is fixed to the crank shaft and one plan of keeping it lubricated.

We shall describe different forms of all these moving parts later on, but here we must confine ourselves more particularly to their relative positions and motions. What we have already said in regard to the relative motions of the crank and the piston also applies to the relative positions of the eccentric and the slide valve. The student should plot out a diagram similar to that on p. 98 for the eccentric and slide valve of the engine model illustrated by the first figure in this Lecture, where the eccentric radius is $2\frac{1}{4}$ inches, and the eccentric rod 6 feet. This will impress upon him the fact that, owing to the greater ratio between the rod and the throw, the slide valve is virtually at the middle of its stroke when the eccentric has moved through a right angle (see Index for pages where other eccentrics are illustrated).



WILKINSON'S VALVOMETER.

Wilkinson's Valvometer.*—By means of this instrument, valves and valve motions in steam and other engines can be set out to actual size, and the points of admission, cut-off, exhaust and compression of steam be determined by simple inspection. The instrument is constructed with two slide bars on which the port openings corresponding to the valves are inscribed full size. The bars move in slots, the intermediate spaces having inscribed on them the port openings in the cylinder and plate. Any form of valve, straight-ported, D-ported, Trick or piston valve can be set-out on the bars to full scale. The travel of each bar can be quickly and accurately adjusted by the following means:—On one side (controlling the expansion valve) is an eccentric of which the sheave can be adjusted to any given throw or degree of eccentricity with the crank; and on the other side (controlling the main valve) is a slotted crank in which the throw can be adjusted by shifting the pin in the slot. The lead of each valve, or its angle of advance on the crank, can be separately adjusted. All adjustments can be measured accurately by a scale of sixteenths marked on the instrument, and the angles of advance and positions of the piston in the cylinder read off on the crank circle. The crank can be set to the back or forward centre for observing the lead, or turned to any position for observing the points of cut-off, exhaust and compression. The action of the steam engine governor in making a late or early cut-off according to the lead is readily shown, for all positions of the governor and link. By changing the lead of the main valve 120° the action of the valve in reversing an engine is readily seen, and all intermediate positions show the effect of notching up by the lever and link. The ports on the valves can be altered to any desired inside or outside lap and any combinations between width and position of ports, and travel and lead of valves set out, and their effects studied.

The instrument is, therefore, of service in the drawing office for designing valve motions and arriving at the best dimensions, and in the erecting shop, for setting and re-setting valves. Being provided with means of demonstrating and measuring the effect of any of the above combinations, the instrument is valuable for demonstrating valve actions and steam and other engines to engineering classes.

* See *The Engineer*, July 13th, 1894. There are many other ingenious devices for illustrating to Science Classes the relative positions of crank, piston, eccentric and slide valve, such as that designed by Mr. J. Kerr Reid, Wh. Sch. Engineering Lecturer, Greenock, and the model made by Messrs. Baird & Tatlock, Renfrew Street, Glasgow; but Wilkinson's valvometer, as made by Nalder Bros., Red Lion Street, London, W.C., is also useful in the drawing office and workshop.

Lecture XIV.– Questions.

1. Make a diagram of the valve and ports of a steam engine with crank and eccentric circles, showing the positions of the crank, of the centre of the eccentric, and of the slide valve, when the crank is on its dead centre. (S. and A. Exam., 1888.)

2. Make a free-hand sketch of the first figure in this Lecture, but place the cylinder on the right hand and the crank on the left hand of your paper. Trace the course of the steam in entering and leaving the cylinder, and write out a complete "Index to Parts."

3. Show, by sketches, &c., how the motion of the piston is converted into that of the crank, and that of the eccentric into that of the slide valve. Why is the eccentric fixed so as to move ahead of the crank?

4. A crank is 1 foot long, while the connecting rod is 6 feet: find graphically how far the piston is from the beginning of its stroke when the crank has moved through 45 degrees from the inner dead centre. *Ans.* 4 inches nearly.

5. In a direct-acting horizontal engine the lengths of the crank and connecting rod are 1 and 5 feet respectively. How far is the piston from the middle of its stroke when the crank is vertical? *Ans.* 1·23 inch.

6. In a direct-acting engine, plot out by a diagram the relative positions of the piston and crank during a stroke, on the supposition that the connecting rod is of infinite length or remains parallel to itself. How is this diagram altered when a definite length is assigned to the connecting rod?

7. What is meant by the "dead centres" in the case of a crank and connecting rod? Sketch four figures in mere skeleton lines, showing a crank, connecting rod, piston rod and piston, and cylinder, when the crank is at each dead centre, and also when the force transmitted through the connecting rod has the greatest turning effect.

8. Sketch an ordinary eccentric in side elevation and in sectional plan. Give an index to the parts, and show how the motion imparted by it is the same as by a crank of the same throw or radius. Why cannot an eccentric be used for converting reciprocating into circular motion? In what cases are eccentrics applied in preference to cranks, and why?

9. Compare the crank with the eccentric. Show that they both produce the same motion. State reasons for employing one or the other in particular cases. (S. and A. Exam. 1889.)

10. Describe, with sketches, the construction of a horizontal direct acting engine, working with high pressure steam and without condensation, showing how the steam is admitted into the cylinder and let out again as required. (S. and A. Exam. 1889.)

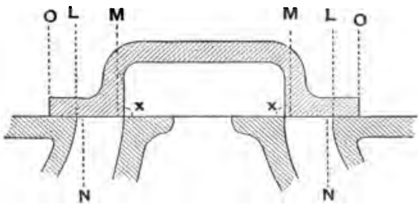
11. Give a longitudinal section through the cylinder and steam-chest of an engine, showing the steam and exhaust ports, the steam slide-valve, the valve-rod, and stuffing-box for the latter. Put the valve in its mid-position. (S. and A. Exam. 1891.)

12. The crank of a direct-acting engine is 2 feet in length and the connecting rod 5 feet. Find the positions of the piston when the crank has described an angle of 60° from the dead centre in both the forward and backward strokes. (S. & A. Exam. 1895.)

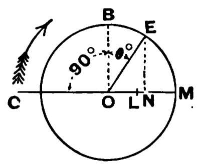
LECTURE XV.

CONTENTS.—Lap, Lead, and Travel of a Slide Valve—Angle of Advance and Throw of an Eccentric—Relative Positions of the Crank and the Slide Valve—Cause of the Unequal Distribution of Steam during the Forward and the Back Stroke.

Lap and Lead of a Valve, &c.—The slide valve shown in the following figure is purposely placed at the centre of its stroke, in order to facilitate an explanation of what is meant by *lap*. The valve, like that in the figure, p. 125, is that known as the Locomotive D Slide Valve. It consists of a hollow box with projecting ends, the lower face being accurately planed and fitted, so as to be steam tight on the valve port face. The hollow arch of the valve just covers the distance between the inner edges of the steam ports, so that the moment the valve cuts off the exhaust from one end of the cylinder, it opens the other end of the cylinder to exhaust.



SECTION THROUGH SLIDE VALVE AND STEAM PORTS.



POSITIONS OF CRANK AND ECCENTRIC.

Now, looking at the left-hand figure, we see the three dotted vertical lines drawn above the valve face at each end of the valve. The distance, O to L, is the amount by which the valve overlaps the steam port at each end. This is termed the *outside lap* of the valve, while the distance between L and M is the amount the valve (when at the end of its stroke) opens the steam port for admission of steam into the cylinder. This distance, LM, is frequently less than the breadth of the steam port, because the same passage serves both for inlet of the steam to, and its exit from, the cylinder; and, seeing that the steam has expanded while

doing work in the cylinder, the larger the opening to exhaust, the less will be the back or obstructive pressure.

The vertical dotted lines drawn from, N, below the valve face near the outside edge of each steam port, indicate the *lead*.

The circle in the right-hand figure is intended to represent the path of the centre of the eccentric pulley, which works the slide valve. The radius, OM, is, therefore, equal to the throw of the eccentric, or half the travel of the valve. Now, supposing the crank to be in the position, OC, or level at the inner dead centre in a horizontal engine (*i.e.*, the piston is just at the commencement of the outgoing stroke), mark off the distance, ON, equal to the outside lap, OL, *plus* the lead, LN, draw NE perpendicular to OM, and join OE; then (neglecting the obliquity of eccentric rod) we have—

OC for the Centre line of the crank.	LM for the Maximum opening to steam.
OE " " " eccentric.	$\theta°$ for the angle, BOE, or the angle of advance.
OL " Lap.	
ON " Lap + lead.	

We thus see that the centre line of the eccentric must be in advance of the centre line of the crank, by $(90° + \theta°)$, where $\theta°$ is called the *angle of advance*.

If there was neither lap nor lead, then the centre line of the eccentric would be at right angles to the centre line of the crank, or the eccentric only 90° ahead of the crank.

Sometimes slide valves have what is termed *inside lap*, that is, an inner projection at each end of the arch of the valve, marked in dotted lines by, x, in the figure. This causes the exhaust to take place later on the one side and to be cut off sooner on the other side of the piston. The effect of this is twofold—(1) a later release causing a higher back pressure, (2) compression before the end of the stroke. The latter effect is useful, as we shall see later on, owing to its assisting in arresting the momentum of the moving piston, piston rod, crosshead, and connecting rod, and thus lessening what would otherwise cause a sudden stress or jerk on the crosshead and crank-pin bearings, and therefore undue wear and tear. More frequently, however, a part of the necessary cushioning is effected by giving "*lead*" to the slide valve, that is, allowing it to open the steam port before the piston has come to the end of its stroke.

In order to impress these various parts and positions of the slide valve, we here enumerate them as definitions.

Lap or cover of a slide valve is the amount by which the edge of the valve overlaps the adjoining edge of the steam port, when the valve is in the middle of its stroke, and is termed *outside* or

steam lap, and *inside* or exhaust lap, according as we refer to the outside or inside of the slide valve.

Lead is the amount of the opening of the steam port at the beginning of the piston's stroke.

Angle of advance of eccentric is the angle by which the centre line of the eccentric stands in advance of that position, which would bring the valve to its mid-stroke when the crank is on the dead point; or, in other words, the angle between the crank and the centre line of the eccentric *minus* 90°.

*The throw of an eccentric** is the distance between the centre of crank shaft and the centre of eccentric pulley.

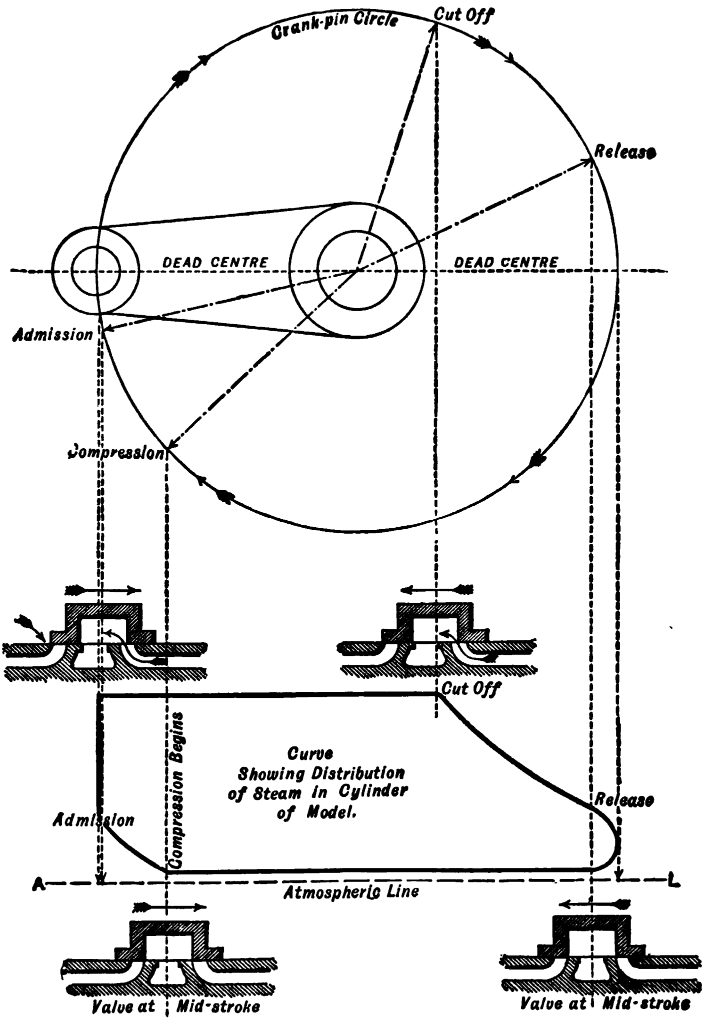
The travel of a slide valve is equal to the distance the valve moves to and fro in one stroke of the piston, or twice (the lap + opening to steam). It is equal to *twice the throw* of eccentric.

Relative Positions of the Crank and Slide Valve.—The following diagram illustrates the four principal points in the motion of the simple D slide valve of the working model explained at the beginning of last Lecture, p.125,as well as the corresponding positions of the crank, and also the probable distribution of steam in the cylinder or "diagram of work."

1. The point of *admission* of steam to the cylinder.
2. The point of *cut off* of steam from the cylinder.
3. The point of *release*, or when exhaust begins.
4. The point of *compression*, or when exhaust stops.

The diagram is self-explanatory, in as far as it shows how each of these points marked on the crank-pin circle is projected on to the "diagram of work" (or piston's stroke) below, with the corresponding positions of the slide valve sketched on the lines of projections. The direction of motion of the crank and of the slide valve at each point is also made clear by arrows. It will be observed that the slide valve is at the same position with respect to the steam ports when beginning to admit steam to the cylinder and to cut off the supply of steam from the same, and that its direction of motion is in each case opposite to the direction of the piston's motion. It is also evident that the slide valve is at the middle of its stroke when release and when compression begins, and that its motion is opposite in each case to that of the piston's motion, as indicated by the straight arrows placed directly above the figures of the slide valve.

* Several authors—*e.g.*, Prof. Goodeve—state that *the throw of an eccentric* is equal to the diameter of the circle described by the centre of the eccentric pulley. The word "throw" is ambiguous, and might be discarded, for it is liable to lead to confusion. See *The Practical Engineer*, Nov. 18, 1887, p. 521.



RELATIVE POSITIONS OF CRANK AND SLIDE VALVE, WITH CURVE SHOWING THE DISTRIBUTION OF STEAM IN THE CYLINDER, WHEN OBLIQUITY OF THE CONNECTING AND ECCENTRIC RODS IS NEGLECTED.

Cause of the Unequal Distribution of Steam during the Forward and the Back Stroke of the Piston.—If the connecting rod of an engine were infinitely long (and therefore remained always parallel to the centre line of the piston's motion), the point of "cut-off," and consequently the distribution of steam, would be equal at both ends of the cylinder; but when the length of the connecting rod (as usually adopted in practice) is only from 2 to 4 times the length of the crank, the distance to the point of "cut off" is considerably later on the forward stroke than on the return or back stroke.

An explanation of the following diagram will render this quite evident.

Consider a case when the slide valve has "outside lap" only, and no "lead."

1. Draw a centre line of the piston's motion, C_3, to 10.

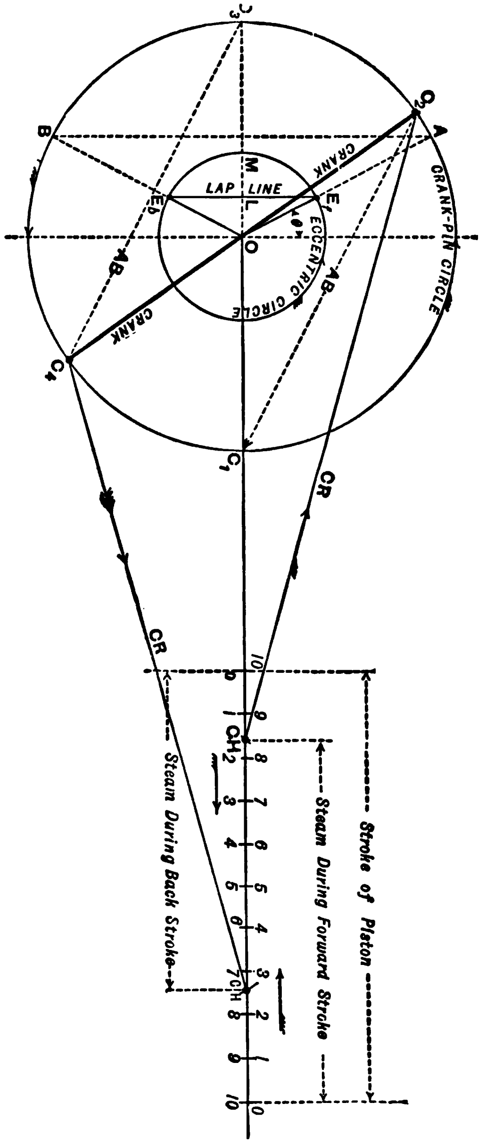
2. With any convenient position, O, as a centre and radius, OC_1, equal to the length of the crank, describe a circle, $C_1C_2C_3C_4$, and let the crank revolve in the direction shown by the arrows on the crank-pin circle.

3. With centre, C_1, and radius equal to the length of connecting rod (in this case = 3 cranks), describe an arc, cutting the centre line of engine in the position, o, furthest from, C_1. With centre, C_3, and the same radius, describe another arc, cutting the same centre line in position 10 nearest to C_1. Then the distance, o to 10, is equal to the piston's stroke. This distance may be conveniently divided into ten equal parts both above and below the centre line, so as to indicate percentages of the stroke during the *forward* and *back* strokes of the piston.*

4. With centre, O, and radius equal to the throw (or eccentricity of the eccentric), describe the inner small circle ME_fE_b.

5. From, O, plot off a distance, OL, equal to the outside lap of the slide valve, and draw through, L, the line, E_fLE_b, at right angles to the centre line of the engine. From O, draw radial lines, OE_fA, and, OE_bB, cutting the crank-pin circle in, A, and, B, and join AB. Then, since the slide valve has no "lead," OE is the centre line of the eccentric when the crank is in the position OC_1, and the eccentric turns round from the position, OE_f, to the position, OE_b, in the operation of moving the slide valve during opening and closing the back steam port; consequently the crank must turn through an equal angle during this operation, *i.e.*, an

* Of course, the positions o and 10 are in reality the centre of the cross-head at each end of the stroke in ordinary engines having a crank and connecting rod. To include the length of the piston rod would extend the figure beyond the limits of the page.



UNEQUAL DISTRIBUTION OF STEAM DURING THE FORWARD AND BACK STROKES OF THE PISTON, DUE TO THE LENGTH OF THE CONNECTING ROD, WHEN THE SLIDE VALVE HAS ONLY OUTSIDE LAP.

angle equal to AOB. The "angle of advance" of the eccentric is indicated by $<\theta>$.

6. With centre, C_1, and radius, AB, describe an arc, cutting the crank-pin circle in C_2, and join O, and C_2, by a thick line. Then, OC_2, is the position of the crank when steam is cut off from the cylinder, *i.e.*, when the centre of the eccentric pulley is in the position E_b.

7. With C_2 as a centre and radius equal to the length of the connecting rod, describe an arc cutting the centre line of the engine in CH (crosshead), nearly midway between positions 8 and 9, above the line, thus showing that steam is cut off at about 85 per cent. of the stroke during the forward movement of the piston and crank.

8. With C_3 as a centre and radius, AB, describe an arc, cutting the crank-pin circle in C_4, and join O, and C_4, by a thick line. Then OC_4 is the position of the crank when steam is cut off from the cylinder during the back stroke of the piston.

9. With C_4 as a centre and radius equal to the length of the connecting rod, describe an arc cutting the centre line of the engine in CH, nearly midway between positions 7 and 8, below the line, thus showing that steam is cut off at about 75 per cent. of the stroke during the backward or return movement of the piston and crank.

LECTURE XV.—QUESTIONS.

1. Sketch in section an ordinary locomotive cylinder D slide valve. Put valve in its middle position over steam ports, (S. and A. Exam. 1887.)

2. What is the lap of a slide valve? Draw a section of a simple slide valve and ports, showing the valve (1) without lap, (2) with lap. Account for the difference in the working of two engines, one of which has lap on the steam side of this valve and the other has not. (S. and A. Exam. 1889.)

3. What effect is produced by putting lap on a slide valve? The lap on the steam side of a slide valve is $1\frac{1}{2}$ inch, that on the exhaust side is $\frac{1}{4}$ inch, and the lead is $\frac{1}{8}$ inch. Find the opening for exhaust which the valve gives at the lower port when the piston is at the top of its stroke. *Ans.* $1\frac{3}{8}$ inch.

4. What is the meaning of the term "*lead*" as applied to a slide valve? Sketch in longitudinal section the steam ports and passages leading to the top and bottom of the cylinder, and place the valve in such a position that the lead is $\frac{1}{4}$ inch, the lap of the valve being 1 inch, marking dimensions. (S. and A. Exam. 1888.)

5. Sketch an eccentric, and describe the several parts. What is the throw of an eccentric? Upon what does the amount of throw depend? What is the angle of advance?

6. Explain the meaning of the following terms by aid of sketches and reference letters:—(1) Outside or steam lap; (2) inside or exhaust lap; (3) maximum opening to steam; (4) travel of valve; (5) lead of valve.

7. The steam port of a cylinder is 3 inches wide, the slide valve has 2 inches outside lap and $\frac{1}{2}$ inch inside lap. Sketch to scale part of the valve and one steam port, and mark the length of the valve face. *Ans.* $5\frac{1}{2}$ inches.

8. If the travel of a slide valve is 6 inches, and the steam or outside lap is $1\frac{3}{4}$ inch, how much will the steam port be opened to steam? *Ans.* $1\frac{1}{4}$ inch.

9. The steam port on the cylinder face is $2\frac{1}{2}$ inches wide, and the outside lap of the slide valve 2 inches: what must be the travel of the slide valve so that it may open exactly three-fourths of the port to steam? Give your reasons why a slide valve is not made to uncover the whole steam port for the admission of the steam into the cylinder, but is made to do so for the exit or exhausting of the steam from the cylinder. *Ans.* $7\frac{3}{4}$ inches.

10. The steam or outside lap is 2 inches, the exhaust or inside lap is $\frac{1}{4}$ inch, and the travel of the valve 8 inches. How much will the port open for steam, and how much for exhaust? *Ans.* 2 inches, and $3\frac{3}{4}$ inches.

11. Make a sketch similar to the second figure in this Lecture, but with the crank revolving in the opposite direction. Mark the positions of admission, cut off, release, and compression on the crank-pin circle. Sketch the position of the slide valve on the steam ports for each of these points, and draw the approximate diagram for the distribution of steam pressures in the cylinder.

12. Taking a direct-acting engine, and disregarding the effect of obliquity of the connecting rod, you are required to assign the proportion of lap to travel of slide valve, in order to cut off steam at $\frac{3}{4}$ of the stroke. Assume travel as $4\frac{1}{2}''$ and lead $\cdot 25''$. *Ans.* Lap $= \frac{1}{4}$ travel of valve.

13. Given that the travel of a slide value is 5 inches, outside, or steam lap $\frac{3}{4}$ inch, and the angle of advance $22\frac{1}{2}°$; find graphically, or otherwise, the position of the crank at the point of cut-off. *Ans.* ·88 of stroke.

14. Given stroke of piston 20 inches, length of connecting rod 5 feet, outside lap equal to twice the opening to steam; make a diagram to scale like the last figure in this Lecture, showing when steam will be cut off during the forward and the back strokes, and account for the difference.

15. Sketch in section the parts of a steam cylinder, and show by means of three separate sketches any form of slide valve which you prefer to illustrate, wherein—(1) The valve has no lap; (2) The valve has lap on the steam side; (3) The valve has lap on both the steam and exhaust sides. In each drawing the valve must be shown in its mid-position. (S. & A. Exam. 1890.)

16. Sketch an eccentric, and rod for connecting it with the slide valve of an engine. Show by a diagram the positions of the crank and eccentric, (1) when steam is admitted into the cylinder, (2) when steam is cut off, the valve having a fixed amount of lap and lead, which you are to allow for in the diagram. (S. & A. Exam. 1891.)

17. What is meant by the lead of a valve? What is the object of lead? How is lead obtained when an eccentric actuates the valve? (S. and A. Exam. 1892.)

18. What are the functions of a slide valve in a steam engine?. Sketch a single ported D slide valve, and show it opening the port by the amount of lead. (S. & A. Exam., 1893.)

19. Define the angle of advance of an eccentric. Show by a diagram the position of the crank and the angle of advance in an ordinary direct acting engine. Sketch separately one usual form of eccentric and strap as made in parts, showing how the separate halves of the eccentric and strap are respectively connected together. (S. & A. Exam., 1893.)

20. What is a slide valve, and for what purpose is it used in a steam engine? Show clearly by sketches the position of both ends of such a valve in relation to the ports when the piston is at the beginning, middle, and end of its stroke (cut-off being at half stroke). (S. & A. Exam., 1894.)

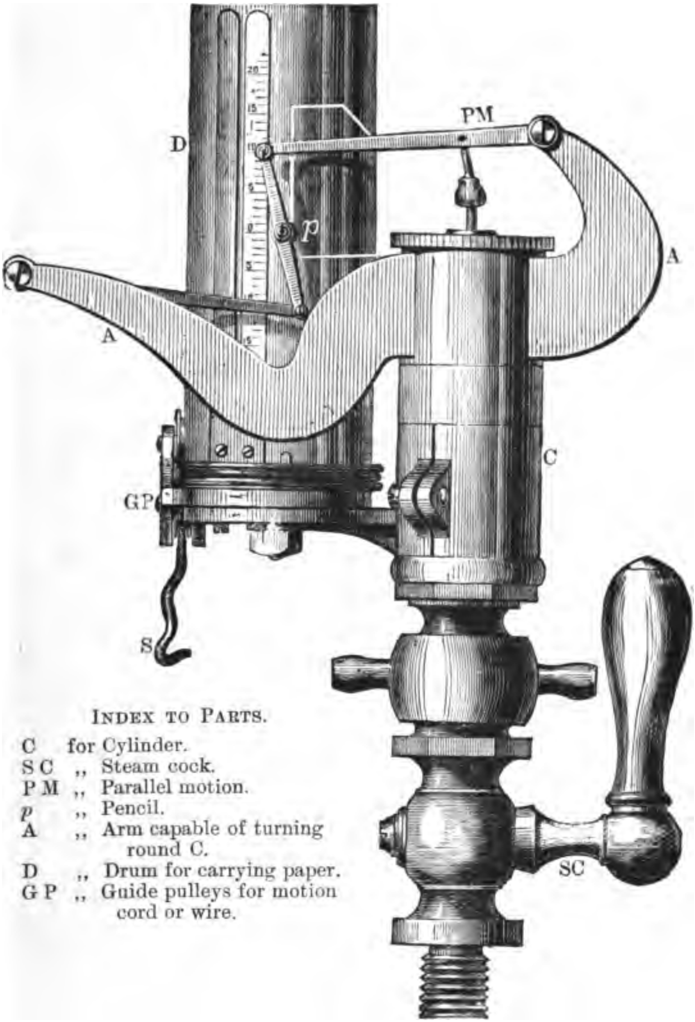
21. Define the "lap" and "lead" of a slide valve, and state the purpose for which each is employed. Sketch in section the cylinder and its ports with the slide valve in the middle of its stroke, and show from your sketch the amount of lap both on the steam and exhaust sides which you have put upon the valve. (S. & A. Exam. 1895.)

LECTURE XVI.

CONTENTS.—Richard's Indicator—Method of taking Indicator Diagrams —Example of a Full-sized Indicator Diagram from a Non-condensing Engine—Effects of Clearance, Compression, Cushioning, Wire-drawing, and Release on the Indicator Diagram.

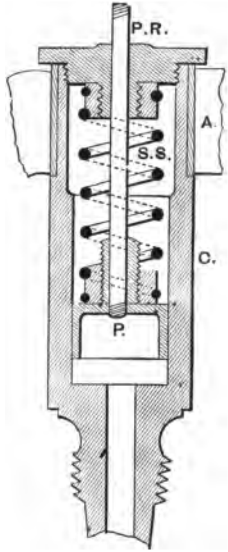
WATT was the first person who fully recognized the importance of gaining some knowledge of the action of steam in the cylinder of an engine, and the first form of indicator was the result of his efforts in that direction. Since Watt's time many important improvements and modifications have been introduced into this useful instrument. We have only space, in an elementary treatise like this, to describe one form of it, and we therefore select the Richard's Indicator as the one most commonly used for speeds up to 100 revolutions per minute.

Richard's Indicator.—When the piston of an indicator has a long travel (which was common in the older forms), the motion of the pencil is jerky and irregular, for the sudden admission of steam causes the pencil to rise too high, and the opening to exhaust brings it down too low, the whole diagram appearing irregular and jagged. This defect is remedied in Richard's indicator by using a strong spring, and decreasing the travel of the piston, the necessary depth of diagram being obtained by multiplying the motion of the pencil, *p*, by means of the parallel motion levers, P M. The arm, A, which carries the parallel motion, P M, is capable of rotating round the cylinder, C, as an axis, so that the pencil may be pressed against or removed from the drum, D, and the tracing of the diagram thus started or stopped at any point. The indicator card is wrapped round this drum, and made fast by the two vertical clips; on one of these a scale is engraved. The drum is rotated by means of the string, S, and its return is effected by a strong horizontal clock-spring fixed inside the drum, D.



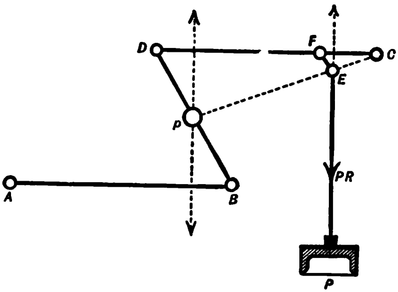
RICHARD'S INDICATOR FOR SLOW SPEED ENGINES.
(See also Index to the figure on next page.)

The following right-hand figure illustrates how the movement of the pencil in the Richard's indicator becomes a magnified movement of the piston, as well as how it is kept parallel to it. The device is simply an adaptation of Watt's famous parallel motion, as applied to his well-known steam engines.



Index to Parts of Cylinder.

P R for Piston rod.	P for Piston.
S S ,, Spiral spring.	A ,, Arm.



Section of Indicator Cylinder.

Parallel Motion for Richard's Indicator.

Two equal bars, AB, and, CD (fixed to the arm, A, which carries the parallel motion—see outside view), are connected by a link, BD, having a metallic pencil, *p*, fixed at its middle. The piston, P, with its piston rod, P R, is connected to the bar, CD, by a link, EF. Usually the point, F, is chosen such that, CD, = 4 times CF. When equilibrium exists—*i.e.*, when the piston, P, has atmospheric pressure above and below it, the link, EF, is parallel to the link, BD, and the line, CE*p*, joining, C, and, *p*, is a straight line. Now, since the point, E, describes a straight vertical line, the pencil, *p*, must necessarily do so also within the limits of its range; and further—

The travel of piston, P : Travel of pencil, *p* :: **CF : CD.**

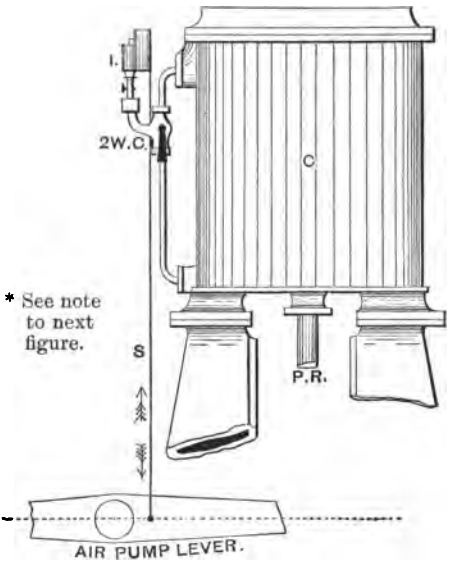
Thus, the movement of the pencil is always kept parallel to the indicator piston, and the travel of the latter is magnified four times, so as to produce indicator diagrams of a handy size for observing the variations in the steam pressure, &c.

Fixing the Indicator.—In most engines a small pipe is fixed outside the cylinders and communicating with both ends.* The indicator is attached to this pipe. The pipe is fitted with a two-way cock, so that a diagram may be taken from either end of the cylinder at pleasure. The figure shows the method of attaching the indicator to an inverted cylinder marine engine.

The string, or steel wire, S, is attached to the air-pump lever, and its travel must be rather less than the circumference of the indicator drum. Before admitting steam into the indicator, the "atmospheric line" should be drawn. This is done by bringing the arm which carries the pencil up to the rotating *drum*, when a horizontal line is drawn, which is marked A L, for atmospheric line, on the diagrams throughout this book.

INDEX.

C	for	Cylinder.
P R	,,	Piston rod.
I	,,	Indicator.
2 W C	,,	Two-way cock.
S	,,	String for turning the indicator drum.



* See note to next figure.

TAKING INDICATOR DIAGRAM.

Indicator Diagrams.—Having studied in Lectures XII. and XIII. the theoretical indicator diagram, we are now in a position to examine and comment upon a few indicator diagrams taken from actual practice, and the effects of clearance, compression, wire-drawing, release, &c.

* The left-hand figure on p. 144 is a section of the cylinder, C, which is made of brass, and one-half square inch in sectional area. It is closed on the top by a cover which forms a guide for the piston rod, P R. The spiral spring, S S, is fixed to the cover and to the piston. A complete set of these springs, suitable for working at different pressures, is usually supplied with the instrument.

The opposite diagram is taken from a horizontal non-condensing engine (sometimes wrongly termed a high-pressure engine). The steam pressure rises almost instantaneously, as shown by the vertical admission line, and is well sustained up to the point of cut-off, the line P C O being perfectly horizontal. At the point of cut-off, C O, a very slight wire-drawing may be seen by the rounded corner, but it is scarcely appreciable, and testifies to the efficiency of the valve gear.* The release of the exhaust steam takes place at the point R, but might, with advantage, have been effected a little sooner. The exhausting of the steam is very effectually carried out, as the back pressure falls quite down to the atmospheric line, A L. The amount of compression shown is too little, and a larger compression would no doubt make the engine work more smoothly at the dead points, for a slight knocking of the connecting-rod bushes was observable. In this engine, however, the piston speed is very slow—viz., 160 feet per minute, so that a large amount of compression is not necessary.

Effects of Clearance.—In actual practice, the piston does not come close up to the end of the cylinder at the end of its stroke, a small space being of necessity left between the piston and the cover, to allow for the wear of the journals and to leave room for any condensed steam or priming that may be present. Besides this, there is the volume of the steam ports between the valve face and the cylinder. This combined space between the piston and the cylinder cover, *plus* the steam ports, is termed *the clearance* of the cylinder. It exercises an important influence upon the expansion of the steam; for it must be filled with steam at the moment of cut off. The ratio of expansion of steam in a cylinder, as hitherto understood by the student, is equal *to the volume of cylinder divided by the volume to point of cut off.*

Or, expansion ratio

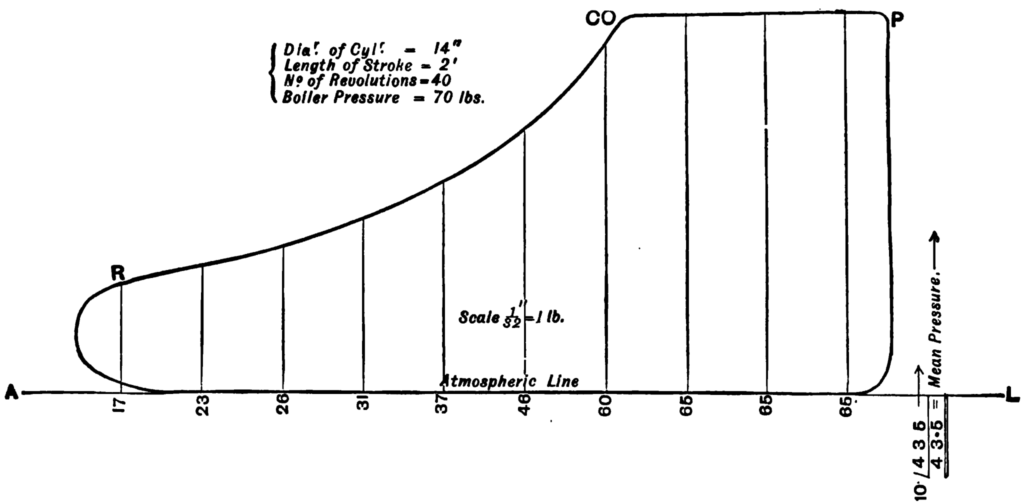
$$= \frac{\text{the volume of cylinder}}{\text{the volume to point of cut off}}$$

$$= \frac{\text{the area of cylinder} \times \text{length of stroke}}{\text{the area of cylinder} \times \text{distance to point of cut off}}$$

$$= \frac{A \times L}{A \times l} = \frac{L}{l};$$

where A = Area of cylinder in square feet or in square inches,
L = Length of stroke in feet or in inches,
l = Length of stroke to point of cut off in feet or in inches.

* See pages 150, 151.



FULL SIZE INDICATOR DIAGRAM, FROM A NON-CONDENSING ENGINE.

This diagram is an exact full size copy of one taken by the author from the Clyde Trust pumping engines working their Armstrong Hydraulic System at the Queen's Dock, Glasgow.

Note.—The plan of attaching the indicator to both ends of a cylinder, as shown in the figure on page 145, although convenient from a mechanical point of view, is not advisable in the case of long cylinders, or where the pipes are exposed to the cooling action of draughts. To obtain accurate diagrams, the indicator should be attached directly to each end of the cylinder by a short large pipe, so as not to throttle or condense the steam, as was done in this case.

If *clearance* be taken into account, the *true* ratio of expansion is much less than this ratio, for it becomes—

$$= \frac{\text{volume of cylinder} + \text{clearance}}{\text{volume to point of cut off} + \text{clearance}}$$

$$= \frac{\text{area of cylinder} \times (\text{length of stroke} + \text{clearance})}{\text{area of cylinder} \times (\text{length of stroke to point of cut off} + \text{clearance})}$$

$$= \frac{A(L+c)}{A(l+c)} = \frac{L+c}{l+c};$$

where c = the necessary length to represent the total clearance volume at the end of the stroke when reducod to the area of the cylinder, A. The lengths, L, l, and c, must be expressed in the same unit, feet or inches.

The difference between $\frac{L}{l}$ and $\frac{L+c}{l+c}$ is obviously greatest with high ratios of expansion, or, with an early cut off, *i.e.*, when, l, is nearly equal to c; hence, with high ratios of expansion, the clearance space should be reduced to a minimum.

EXAMPLE I.—Consider, in the first place, an ordinary case, such as would occur in good practice. Given an engine with a stroke of 4 feet, steam cut off at half-stroke, and the clearance volume equal to $\frac{1}{10}$ the volume of the cylinder, or say 10 per cent.:—

Here L = 4 feet, l = 2 feet, c = 0·4 foot.

If we neglect clearance—

$$\text{The Ratio of Expansion} = \frac{L}{l} = \frac{4'}{2'} = 2.$$

Or, the steam is represented as expanding to twice its volume at point of cut off.

If we consider clearance, then—

$$\text{The Ratio of Expansion} = \frac{L+c}{l+c} = \frac{4'+\cdot4'}{2'+\cdot4} = 1\cdot8\dot{3}.$$

Or, the steam actually expands $1\cdot8\dot{3}$ times. Now, the difference between 2 and $1\cdot8\dot{3}$ does not appear at first sight to be so very great; but we must remember that this difference occurs at every stroke; consequently, in the course of an hour's steaming, the difference in the reckoning up of the total volume of steam used would be considerable.

EXAMPLE II.—Now let us try an extreme case, such as would be considered *bad* practice. Given an engine with a stroke of 4 feet, with steam cut off at $\frac{1}{10}$ of the stroke, and the clearance volume $\frac{1}{10}$ of the volume of cylinder, or 10 per cent., as before:—

Here L and c are the same as before, and l = 0·4 foot.

If we neglect clearance—

$$\text{The Ratio of Expansion} = \frac{L}{l} = \frac{4'}{\cdot 4'} = 10.$$

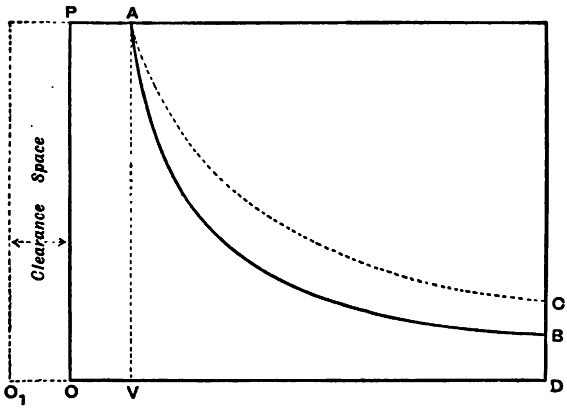
Or, the steam is represented as expanding to *ten* times its volume at point of cut-off.

If we consider clearance, then—

$$\text{The Ratio of Expansion} = \frac{L+c}{l+c} = \frac{4'+\cdot 4}{\cdot 4+\cdot 4} = 5\cdot 5.$$

Or, the steam actually expands *five and a half times*, instead of *ten* times, as misrepresented above, when we neglect clearance.

The student will now be able to appreciate the effect of clearance on the form of the expansion curve. In the following figure the cut off is represented as taking place at $\frac{1}{8}$ of the stroke, and the clearance as equal to $\frac{1}{8}$ of the volume of the stroke.

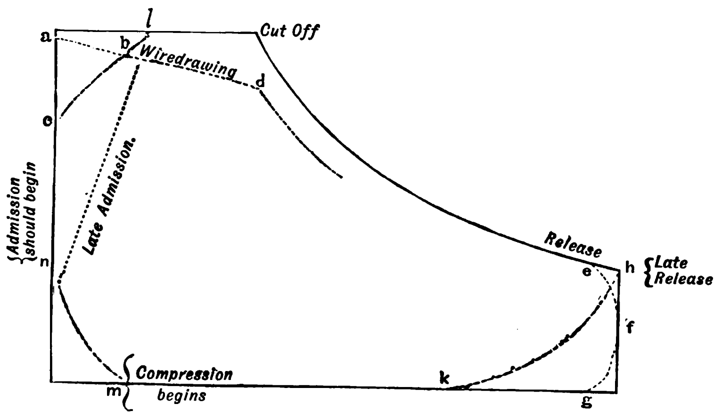


EFFECT OF CLEARANCE ON EXPANSION CURVE.

AB is the curve which would be followed, according to Boyle's law, by the steam expanding 8 times with a volume, OV ($\frac{1}{8}$OD), and pressure, OP (*i.e.*, neglecting clearance). AC is the curve of expansion, which would be followed, according to the same law, by the steam when the clearance space is taken into account, the volume being now O_1V, the pressure the same as before, and the expansion then becomes only $4\frac{1}{2}$ times. This shows the importance of taking the clearance into account.

In practice it is impossible to avoid clearance altogether, but the losses arising from it may be considerably reduced by compression of a portion of the steam on the exhaust side.

Compression and Cushioning.—Compression is effected, as we pointed out in Lecture XV., by closing the exhaust port before the piston has completed its stroke, when any steam still remaining in the cylinder is compressed into the clearance spaces. If the compression were so great as to raise the pressure of the steam in the clearance spaces to the initial pressure of the steam, loss from the clearance spaces would be avoided, since they would already be full of steam at the initial or entering pressure, when fresh steam was admitted for the return stroke. The mean pressure of steam would, however, be reduced by such excessive compression. The useful extent of cushioning, considered with reference to the motion of the engine alone, depends chiefly on the speed of the engine. In very fast-running engines a large amount of cushioning is necessary, in order to arrest the momentum of the moving parts gradually, and reverse the direction of motion without shocks; but if the piston speed be slow, a less compression will suffice to keep the motion smooth and free from jerks. These considerations limit the amount of compression to be used for any particular case. In engines having a high ratio of expansion and great piston velocity, the exhaust steam might with advantage be compressed up to the initial pressure, but in other cases, a moderate compression is all that can be recommended. The effect of compression on the indicator diagram is a sudden rise in the exhaust or back pressure line just before steam enters, and is shown on the following diagram by the curved line *mn*.



EFFECTS OF COMPRESSION, WANT OF LEAD, WIRE-DRAWING, AND RELEASE.

Compression up to the initial pressure of the steam has a

further advantage in unjacketed cylinders, viz., that the cylinder becomes heated up to the initial temperature of the steam by the work done upon it, and condensation of the entering steam may, therefore, be greatly reduced.

It is necessary in practice, especially with high-piston speeds and low-pressure steam, to open the steam port before the piston has reached the end of its stroke, in order to assist the cushioning and to maintain the full initial pressure as the piston moves forward. This amount of opening of the steam port is termed the "lead" of the slide valve. If no lead be given to the valve, the steam port is not sufficiently open when the piston begins to move forward, and the full pressure of steam does not come upon the piston until it has travelled over a part of the stroke as indicated by a rounded corner, *cbl*, on the diagram, or, if very marked, it might be indicated by a line joining, *n*, and, *l*.

Wire-drawing.—When the steam, through insufficiency of valve opening, contracted ports, or throttling, is prevented from following up the piston at full pressure, it is said to be *wire-drawn*, and its effect upon the indicator diagram is the fall of pressure shown by the dotted line, *ad*. With a common slide valve, actuated by an ordinary eccentric, a certain amount of wire-drawing will always take place at the point of cut off, due to the slowness with which the valve closes the port. This is clearly exhibited in the diagrams of all engines fitted with such valves, by a rounded corner at the point of "cut off." A perfect cut-off valve should open quickly, and remain open until the point of cut off, then close quickly. These conditions are not fulfilled by any ordinary slide valve and eccentric, but there are several special devices, such as the Pröell, the Robey, and the Corliss valve gears, which are wonderfully perfect in their action, and which were all exhibited in action at the late International Exhibition, Glasgow, in 1888.

Release.—Besides admitting steam before the end of the stroke, it is also necessary to release the steam on the other side of the piston before the end of the stroke, in order to prevent excessive back pressure. This has the effect of rounding the right-hand corner of the diagram, as shown by the line, *efg*, showing a very small loss, whereas, if steam be carried to the end of the stroke before exhausting, the diagram will take the form shown by the line, *hk*, and excessive and wasteful back pressure will be the result.

Lecture XVI.—Questions.

1. Sketch and describe Richard's indicator, showing how it is applied in obtaining the mean pressure in a steam cylinder.

2. Define wire-drawing and clearance as applied to a steam engine. How are the effects of wire-drawing and of clearance shown on an indicator diagram? Why is wire-drawing to be avoided, and why is clearance necessary? How many cubic feet and lbs. of steam (see Table, p. 107) will be required per hour for a cylinder 40" diameter, 36" stroke, cut off at $\frac{1}{4}$ stroke with a clearance at each end equal $\frac{1}{15}$ of volume of stroke, when making 60 revolutions per minute, and supplied with steam of 100 lbs. pressure absolute. *Ans.* 78,300 cubic feet per hour; 18,064 lbs.

3. Explain the effects of "lap," "lead," "cushioning," "wire-drawing," and "release," on the indicator diagram, making such sketches as may be necessary to render your answer clear. Mark also the points of "admission" and "cut off."

4. Draw the normal indicator diagram of a non-condensing engine, and trace the changes in outline produced by the principal causes which may, in practice, detract from the efficiency of the engine.

5. Describe, with such sketches as you think necessary, the operation of taking an indicator diagram from a horizontal engine, saying how you would connect the apparatus with some moving part such as the crosshead. Make a diagram, showing the relative positions of the crank pin and centre of the eccentric pulley at the time, (1) when steam enters the cylinder, (2) when it is cut-off, (3) when compression begins. In what manner are the width of the ports, the lap of the valve, and the throw of the eccentric related together?

6. The diameter of a cylinder is 50", and the stroke 5'. The total clearance at each end is equal to 9817·5 cubic inches, while the distance between the piston and the cylinder covers at the ends of the stroke is 1". What fraction or percentage of the volume of stroke does the total clearance amount to, and what fraction of this clearance is occupied by the steam port? *Ans.* $\frac{1}{12}$ or $8\cdot\dot{3}$ per cent., and $\frac{4}{5}$ or 80 per cent. of this clearance is in each steam port.

7. The diameter of a cylinder is 100 inches, length of stroke 6 feet. Total clearance to be 5 per cent. of volume of stroke. The distance between piston and cylinder covers to be 1 inch at end of stroke. Find the volume occupied by each steam port. If steam be cut off at half stroke, find the true ratio of expansion. *Ans.* 11·82 cubic feet; $\frac{21}{11}$, or 1·90.

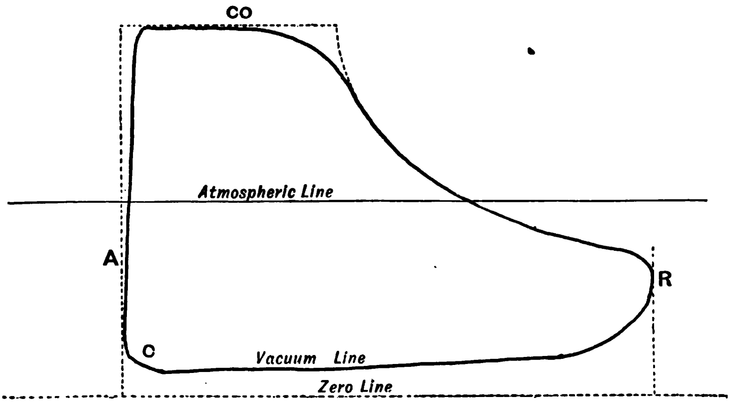
8. A non-condensing engine is using steam at 42 lbs. per square inch above the atmosphere—the length of the stroke is 6 feet, and steam is cut off at $\frac{1}{3}$ stroke—draw an approximate diagram (scale $\frac{1}{24}$) marking points of release and compression, and showing the direction of motion of the piston by arrows. Find by calculation the mean pressure. *Ans.* 24·9 lbs. above atmosphere, or 39·9 lbs. absolute.

9. What is meant by the terms *clearance* and *cushioning*? At what part of the stroke does cushioning occur? Show by a diagram the manner in which the slide-valve produces cushioning. (S. and A. Exam. 1891.)

LECTURE XVII.

CONTENTS.—Indicator Diagram from a Condensing Engine with Defects —Nominal Horse-power—Indicated Horse-power; with Formulæ and Examples.

IN our last Lecture we gave an example of an indicator diagram taken from a non-condensing engine, and we also pointed out the general effects produced on an indicator diagram by compression, lead, wire-drawing, and late or early release. We might multiply these examples to any extent by selecting specimens from atmospheric, single-acting non-condensing, compound, triple, and quadruple expansion engines; but, in an elementary manual like this, all that we can reasonably expect to do is to give the student a correct idea of what a diagram is, how it is taken, and how it is used to find the horse-power in the cases of a non-condensing and a condensing engine respectively. Before explaining how to find the horse-power of an engine, we shall, therefore, consider a diagram taken from a condensing engine which presents a few defects.



INDICATOR DIAGRAM FROM A CONDENSING ENGINE.

First.—The *lead* is insufficient. This is seen by the sloping away of the admission line from the vertical at A. Had the valve been

set to give sufficient lead, the admission line would have coincided with the vertical dotted line, since the non-coincidence of these lines cannot be due in this instance to wire-drawing of the steam in the steam passages; for when once the full pressure comes on the piston, it is fully sustained, as shown by the horizontal line, until the point of cut off at CO, where the usual wire-drawing is indicated by the rounded corner.

Second.—The *release* takes place rather late, as shown at R, by the gently sloping down curve instead of by a more vertical one with sharper corner, and a vacuum line more parallel to the zero line.

Third.—The *compression* is too little, as shown by the sharp corner at C. Had the exhaust been cut off sooner, or if more lead had been given to the valve, this corner at C would have been much more rounded than it is.

It will be observed that the vacuum line falls far below the atmospheric line, but not quite down to the zero line or perfect vacuum line. The vertical distance between the atmospheric line and the zero line is 1 inch, and this distance corresponds to a difference of pressure of one atmosphere, or 15 lbs. The nearest approach of the exhaust or vacuum line to the zero line is at the beginning of the compression corner at C, which measures $\frac{1}{8}''$, thus showing that the least back pressure during exhaust was about 2 lbs. absolute, while at the bottom of the release corner, R, it measures $\frac{3}{16}$ inch, or about 3 lbs. of back pressure. The initial pressure of the steam, as indicated by the vertical distance from the zero line to the horizontal line at CO, a distance of $1\frac{7}{8}''$, is about 28 lbs. absolute. The cut off takes place at about $\frac{1}{3}$ of the stroke, but it is difficult to say precisely what its exact position is, owing to the round corner caused by wire-drawing, produced by the slowly closing slide valve. Had an instantaneous cut-off valve been used, the curve would have followed the dotted line.

Horse-power.—The student is now in a position to understand how the horse-power of an engine may be calculated by aid of the indicator diagram. We have already explained the meaning of the units horse-power and foot-pound, but it will not be out of place to narrate briefly one version of the story as to how the former unit came to be used by engineers.

Since the steam engines introduced by Watt were employed to a large extent in substitution for the work formerly done by horses, he found it necessary to be able to give his customers some idea of their capabilities; or, in other words, to state how many horses his engines would relieve. From a number of experiments, it was found that an average horse was capable of exerting a power equivalent to 22,000 foot-pounds of work per minute. Watt

determined to give thorough good value for the money paid for his engines; consequently, he is reported to have decided to give them 50 per cent. more power than the power of an average horse, for each Nominal horse-power. He therefore added 11,000 foot-lbs. to the 22,000 foot-lbs., which made 33,000 foot-lbs., and intimated that every horse-power developed by his engines would be capable of exerting that amount of work per minute.

What is, therefore, technically understood by engineers as a *horse-power*, is the rate of doing work corresponding to 33,000 foot-lbs. per minute, and the power of steam engines has ever since Watt introduced the term been calculated on this basis.

Watt found that in his engines he usually obtained a mean effective pressure of about 7 lbs. per square inch in the cylinder, and he estimated the power of his engines by assuming that value for the mean nett or effective pressure. The horse-power thus estimated he termed *Nominal* horse-power (N.H.P.), and in practice that power was usually obtained. When, however, increased steam pressures came into general use, the mean pressure of steam in the cylinder could no longer be assumed at 7 lbs., and consequently the nominal horse-power was often far below the actual horse-power. In commerce, however, the term nominal horse-power had been so much used that commercial men understood the size, and therefore the value, of an engine much better when its nominal horse-power was spoken of than its actual power, and, therefore, the term was retained for a long time, and is even yet still used for some classes of engines, such as those used for agricultural purposes. As unfair competition often takes place between different manufacturers, owing to the use of this term, it is fast falling into disuse, and should be altogether abandoned, as misleading and worse than useless.

The actual power exerted in the cylinder of an engine cannot be obtained until we know the mean effective pressure of steam in the cylinder. In order to ascertain this, we must take an indicator diagram from the cylinder by means of the indicator in the manner described in the last Lecture. The horse-power obtained by this means is termed the *Indicated* horse-power, and when the horse-power of engines is spoken of, it is the indicated horse-power which is understood unless otherwise stated, and the letters I.H.P. are placed after the amount.

Referring once more to the indicator diagram described in the last Lecture at p. 146, the first thing to be done is to ascertain the mean pressure. This is done, as we saw in Lectures III. and XIII., by dividing the diagram into a number of equal parts, and measuring the various pressures at each point of division by means of the scale to which the diagram is traced. Engineers usually

divide indicator diagrams into 10 equal parts, by leaving half of a part at each end, as has been done in this instance.

This method of dividing off the figure is the same as if we had divided the diagram into 10 equal parts, commencing with the line of admission, and then measured the height of the pressure ordinates midway between each division. The scale to which this diagram has been drawn is $\frac{1}{32}$ inch = 1 lb. pressure, and the various pressures at each point of division have been printed opposite to them along the atmospheric line, then totalled, and the mean pressure found by dividing the sum by 10 (the number of parts). This gives a mean nett or effective pressure, in this instance, of 43·5 lbs., with a constant back pressure of one atmosphere, or 15 lbs., seeing that the exhaust line coincides with the atmospheric line.

In Lecture XIII., p. 120, we explained that—

The Work done in foot-lbs. in one stroke in a steam-engine cylinder = Mean effective pressure in lbs. per square inch (p) × *Length of stroke in feet* (L) × *Area of cylinder in square inches* (A)—

$$= p \times L \times A.$$

Consequently, the work done in any number of strokes per minute (N) *is simply the above quantity multiplied by* N (or pLAN), and, therefore, the *horse-power is this latter quantity divided by the value of a horse-power, or* 33,000 *foot-lbs.* per minute.

Or, to put it generally in the form of an equation or formula—

$$\text{Indicated Horse-power} = \frac{pLAN}{33{,}000}.$$

This formula is easily remembered, since the numerator forms the simple word "pLAN." It is, however, not a good "plan" to merely remember a formula, unless the complete reasons for the combination of the different steps by which the formula is arrived at are thoroughly understood; we therefore again remind the student that—

Work done by any agent is = the resistance overcome (*or effective pressure applied*) × *the distance through which it acts.*

Consequently, the work done upon a steam-engine piston every minute must be = *the total effective pressure* × *the distance travelled by the piston every minute.*

Let p = the mean pressure of steam in lbs. per square inch.
,, A = the area of the cylinder in square inches.
,, L = the length of the stroke in feet.
,, N = the number of strokes per minute = revolutions × 2.
,, I.H.P. = the indicated horse-power of the engine.

Then, the total mean pressure on the piston $= Ap$, lbs.
Also, the distance travelled by piston per minute $= LN$ ft.,
And, therefore, the work done per minute $= ApLN$ ft.-lbs.

$$\therefore \text{ The I.H.P.} = \frac{ApLN}{33{,}000}.$$

This formula is precisely the same as the one given above viz.—

$$\text{I.H.P.} = \frac{pLAN}{33{,}000},$$

the only difference being that the letters are placed in the natural order for following out the principle upon which the formula is based, whereas in the former case they were written in the order most likely to help the memory.

EXAMPLE I.—Applying our formula to find the horse-power of the engine from the diagram at p. 146, and the data given there, we get—

$$\text{I.H.P.} = \frac{ApLN}{33{,}000} = \frac{153{\cdot}9 \times 43{\cdot}5 \times 2 \times 80}{33{,}000} = 32{\cdot}45.$$

The diagram only gives the mean pressure on one side of the piston; but in practice it is usual to take the mean of two diagrams—one taken from each end of the cylinder. If there be two or more cylinders, the power developed in each has to be added together, in order to obtain the total horse-power.

In all practical cases, the area of the piston rod should be taken into account. For example, where the piston rod comes out at the crank end of the cylinder only, then—

the nett area = total area of cylinder less half the area of piston rod.

When it protrudes at both ends, then—

the nett area = total area of cylinder less the area of piston rod.

EXAMPLE II.—What must be the diameter of a cylinder to develop 100 I.H.P. at 100 revolutions per minute, with steam giving a mean effective pressure of 33 lbs. per square inch, length of stroke 2 feet, and diameter of piston rod $2\frac{1}{2}$ inches?

Let A = the gross area of piston, including piston rod.
,, A_1 = the nett area of piston, neglecting piston rod.
,, A_2 = the area of piston rod.
,, d = gross diameter of piston, including piston rod.
,, d_1 = the nett diameter of piston, due to area A_1.
,, d_2 = the diameter of piston rod.

First, consider the case in which the area and diameter of the piston rod are neglected. Here A_1 represents nett area of piston.

Then by Formula—

$$\text{I.H.P} = pLA_1N$$

$$100 = \frac{33 \times 2' \times A_1 \times 100 \times 2}{33{,}000}$$

$$250 = A_1 \text{ (area in sq. inches)}$$

$$\therefore 250 = \frac{\pi}{4}d_1^2 = \cdot 7854 d_1^2$$

$$\frac{250}{\cdot 7854} = d_1^2 = 318 \cdot 32$$

$$\therefore \sqrt{318 \cdot 32} = d_1 = \underline{17 \cdot 8} \text{ inches}$$

Or, putting A_1 on one side—

$$A_1 = \frac{(\text{I.H.P}) \times 33{,}000}{pLN}$$

$$A_1 = \frac{100 \times 33{,}000}{33 \times 2' \times 100 \times 2}$$

$$A_1 = 250 \text{ sq. inches}$$

$$\frac{\pi}{4}d_1^2 = 250$$

$$d_1^2 = \frac{250}{\cdot 7854} = 318 \cdot 32$$

$$d_1 = \sqrt{318 \cdot 32} = \underline{17 \cdot 8} \text{ inches}$$

Then, 17·8 inches is the diameter of cylinder required, neglecting the piston rod.

Second, consider the case in which the piston rod, $2\frac{1}{2}''$ diameter, protrudes at each end. It is evident that the steam produces no propelling effect on the piston rod; consequently, its area must be added to the area of the piston upon which the steam acts, in order to arrive at the gross area or practical diameter of the cylinder.

The nett area of piston (as before) $= A_1 = \frac{\pi}{4}d_1^2$.

The area of piston rod . . $= A_2 = \frac{\pi}{4}d_2^2$.

The sum of these areas . $= A = A_1 + A_2 = \frac{\pi}{4}(d_1^2 + d_2^2)$.

But the gross area of piston $= A = \frac{\pi}{4}d^2$.

$$\therefore \frac{\pi}{4}d^2 = \frac{\pi}{4}(d_1^2 + d_2^2).$$

Divide both sides of equation by $\frac{\pi}{4}$, and we get—

$$\begin{aligned} d^2 &= d_1^2 + d_2^2. \\ d^2 &= 17 \cdot 8^2 + 2 \cdot 5^2 \\ &= 318 \cdot 32 + 6 \cdot 25 = 324 \cdot 57. \\ \therefore d &= \sqrt{324 \cdot 57} = \underline{18} \text{ inches.} \end{aligned}$$

Or, we might have at once taken the nett area of the piston as found before—viz., $\frac{\pi}{4}d_1^2 = 250$ square inches—and have added to this the area of the piston rod, $\frac{\pi}{4}d_2^2 = \cdot 7854 \times 2 \cdot 5^2 = 4 \cdot 9$ square inches, which gives a gross area $= \frac{\pi}{4}d^2 = 254 \cdot 9$ square inches, and

from this total area found the diameter d by dividing by $\frac{\pi}{4}$, and extracting the square root.

Thus :—

$$\frac{\pi}{4}d^2 = \frac{\pi}{4}d_1^2 + \frac{\pi}{4}d_2^2$$
$$= 250 \text{ square inches} + 4\cdot9 \text{ square inches.}$$
$$= 254 \text{ square inches.}$$
$$\therefore d = \sqrt{\frac{254}{\cdot7854}} = \underline{18} \text{ inches.}$$

Third, consider the case in which the piston rod protrudes only at one end, which is commonly the case with small engines.

Here, in order to get the mean power developed from both ends of the cylinder, we would have to divide the area of the piston rod by 2, and *subtract* this mean area from the gross area of the piston; consequently, to get the gross area of the piston from the given power and the other data, *we have to add half the area of the piston rod to the nett or effective area of the piston*—

i.e.,
$$A = A_1 + \frac{A_2}{2}.$$

Or,
$$\frac{\pi}{4}d^2 = \frac{\pi}{4}d_1^2 + \frac{\pi d_2^2}{4 \times 2}.$$
$$,, \quad = 250 \text{ square inches} + \frac{4\cdot9}{2} \text{ square inches.}$$
$$,, \quad = 252\cdot45 \text{ square inches.}$$
$$\therefore d = \sqrt{\frac{252\cdot45}{\cdot7854}} = \underline{17\cdot9} \text{ inches.}$$

Or,
$$d^2 = d_1^2 + \frac{d_2^2}{2}.$$
$$,, = 318\cdot32 + \frac{6\cdot25}{2}.$$
$$\therefore \quad = \sqrt{321\cdot} = \underline{17\cdot9} \text{ inches.}$$

The difference between 17·9 and 17·8 inches may at first sight seem small and scarcely worth all this trouble, but the student must bear in remembrance that the horse-power varies directly as the nett area of the cylinder, and, consequently, as the square of the diameter, or as $17\cdot9^2$ to $17\cdot8^2$, which gives a difference of about 1 per cent. The difference of a tenth of an inch in the diameter would, therefore, mean a considerable difference in the horse-power in the case of large engines.

In ordinary examination questions it is, however, not usual to state the diameter of the piston rod, or to take any account

of its area when calculating the horse-power. To illustrate this fact, we select the first question from the 1888 Science and Art Examination Elementary Paper in "Steam," which we give verbatim.

EXAMPLE III.*—A winding engine performs 188,156 units of work per minute, and has a cylinder $20\frac{1}{2}$ inches in diameter, the stroke of the piston being 2 feet 10 inches, and the number of strokes per minute being 15. What should be the mean pressure per square inch exerted by the steam on the piston, neglecting loss of work by resistances? (Take $\pi = \frac{22}{7}$.)

By formula for the principle of work,

$$\textit{The work done per minute} = p\text{LAN}.$$

$$188{,}156 = p \times 2\frac{10'}{12} \times \frac{\pi}{4}d^2 \times 15.$$

$$188{,}156 = p \times \frac{34}{12} \times \frac{1}{4} \times \frac{22}{7} \times 20\cdot5 \times 20\cdot5 \times 15.$$

$$\therefore p = \frac{\overset{\overset{\overset{201\cdot24}{\cancel{1006\cdot2}}}{\cancel{17105\cdot1}}}{\cancel{188{,}156}} \times \overset{\overset{2}{\cancel{6}}}{\cancel{12}} \times \overset{2}{\cancel{4}} \times 7}{\underset{\cancel{17}}{\cancel{34}} \times 1 \times \underset{\cancel{11}}{\cancel{22}} \times 20\cdot5 \times 20\cdot5 \times \underset{\cancel{5}}{\cancel{15}}}$$

Note.—In such a question as this, involving as it does the multiplication and division of a large number of figures, the examiner would not expect candidates to find the exact result to many places of decimals by ordinary multiplication and division. He would, I believe, be better satisfied with, and give full marks for, an approximate answer, if the student showed that he thoroughly understood the principles involved in the question. Such examinations as that in "*Steam*" are rather for the purpose of drawing out the student's knowledge of principles of work and heat, &c., than of testing expertness and great accuracy in working out long arithmetical questions. Unfortunately, in this question the numbers are not very well suited for direct and exact cancelling; but we observe that we may simplify the fraction considerably by dividing 12 in the numerator and 22 in the denominator by 2; also by dividing 4 and 34 by 2. Then 11 goes out of 188,156 and 17 out of this quotient, leaving 1006·2 in the numerator. Again, 3 will divide out of 6 in the numerator and 15 in the denominator,

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* There is one thing about this question which rather puzzles a practical engineer—viz., How does the winding engine, having but one cylinder, get over the dead centres at a speed of only 15 strokes per minute? Surely 150 strokes per minute would be nearer the actual requirements.—*A. J.*

and finally 5 will divide out of 1006·2 in the numerator and 5 in the denominator, leaving—

$$p = \frac{\overset{\overset{8\cdot05}{\cancel{40\cdot25}}}{\cancel{201\cdot24}} \times 2 \times 2 \times 7}{\underset{4\cdot1}{\cancel{20\cdot5}} \times \underset{4\cdot1}{\cancel{20\cdot5}}}$$

Here, again, 5 will divide out of 201·24 and 20·5, and 5 will again divide out of 40·25 and 20·5, leaving—

$$p = \frac{8\cdot05 \times 28}{4\cdot1 \times 4\cdot1} = \underline{13\cdot4} \text{ lbs. per square inch.}$$

Students will find that they can arrive at the result much more rapidly, and with far less chance of making an error, by adopting the above "step by step" division or cancelling method in such questions, than by multiplying out all the figures in the numerator and in the denominator and then dividing by long numbers. Should they make a mistake anywhere, they will also find it out more easily.

The advice which we have to give in connection with the solution of all elementary questions relating to work done per minute or horse-power is—

First.—To state the question generally in the form of an equation, as we have done in each of these three examples.

Second.—To substitute all the numerical values given in the question for their corresponding letters in the formula.

Third.—To arrange the equation with the unknown quantity only on one side, and all the numerical figures on the other.

Fourth.—To cancel out from numerator and denominator by easy steps, as we have done in the last case, and then reduce the simplified fraction to a whole number or decimal.

Fifth.—Put down the result opposite to the letter corresponding to the quantity required, and mention the unit by which it is reckoned.

We shall not enter here into all the necessary corrections required for clearance, back pressure, dry or wet steam, &c., as a knowledge of these variations cannot be expected from first year or junior students. We here assume that the mean effective pressure is given, and that it has been found by the most accurate method, or, if it has to be found from the initial pressure, the point of cut off, and the stroke, that the method adopted by Watt and explained in Lectures XII. and XIII., is followed by the student. Further, we have only space to make a passing remark to the effect that the "Indicated Horse-power" does not represent the

nett or effective horse-power given off at the engine fly-wheel or crank shaft, for a certain percentage of the I.H.P. or horse-power developed in the cylinder is absorbed or spent in moving the engine itself.

For example, in a first-class simple non-condensing engine of the very best make, 10 to 15 per cent. of the I.H.P. is thus absorbed when working at full power. In the case of a marine engine, if we include the whole of the pumps, shafting, and screw propeller, it is seldom that more than 50 per cent. of the I.H.P. is left free for the propulsion of the vessel, the other half of the power being absorbed in overcoming friction and in working the various parts of the engine and its attachments. This nett or effective horse-power is termed Brake Horse-power, and in the case of small engines up to, say, 50 B.H.P., it can be easily ascertained by aid of an apparatus termed a Dynamometer. In regard to this, also, we must refer the student to Lecture XVI. of the author's more advanced text-book.

LECTURE XVII.—QUESTIONS.*

1. Explain the difference between a non-condensing engine and a condensing engine. Show by a diagram that more work is obtained from a given quantity of steam in the latter class of engines.

2. Draw the normal indicator diagram of a condensing engine, and trace the changes in outline produced by the principal causes which may, in practice, detract from the efficiency of the engine.

3. The piston of a steam-engine cylinder is 40" diameter, and the stroke 3', while the mean effective pressure is 26 lbs. per square inch. Find the work done in foot-pounds in each revolution of the crank. *Ans.* 196,030 foot-pounds.

4. Define the horse-power of an engine. Explain the method adopted for measuring the work actually done in the steam cylinder of an engine. Write down the formula by which the horse-power of an engine is obtained.

5. In a steam engine the diameter of the steam cylinder is 50 inches, the length of stroke is 7 feet, the number of revolutions is 25 per minute, and the mean effective pressure of the steam is 11·3 lbs. Find the horse-power of the engine. *Ans.* 235·3

6. In a beam engine the total mean pressure of the steam on the piston is 20 tons, and the length of the crank is 2½ feet; what is the horse-power when the crank shaft makes 30 revolutions per minute? *Ans.* 407·2.

7. The cylinder of a steam engine is 3 feet 6 inches in diameter, the length of stroke is 5 feet, and the crank makes 30 revolutions per minute; what is the I.H.P. of the engine, the mean effective pressure of the steam in the cylinder being 10 lbs. on the square inch? *Ans.* 126.

8. What would be the indicated horse-power of a high-pressure, non-condensing steam engine, in which the mean effective pressure of the steam is 25 lbs. per square inch, the diameter of the cylinder 10 inches, and the length of stroke 18 inches, when running at 120 revolutions per minute? (S. and A. 1887 Exam.) *Ans.* 21.42 H. P.

9. What diameter of cylinder will develop 50 I.H.P. with 4 feet stroke, 40 revolutions per minute, and a mean effective steam pressure of 30 lbs. per square inch. *Ans.* 14·78 inches.

10. The diameter of a cylinder of a non-condensing engine is 18 inches, the length of stroke is 2 feet 6 inches, the mean pressure of the steam is 20 lbs. on the square inch above the atmosphere. Find the number of revolutions per minute when the engine develops 27 H.P. (S. and A. 1888 Exam.) *Ans.* 70 strokes, or 35 revolutions.

11. What is the horse-power of an engine whose cylinder is 5' 3" diameter, stroke 48", mean effective steam pressure on piston 17·5 lbs. per square inch, and revolutions 57 per minute. *Ans.* 753·8.

12. The diameter of the cylinder of an engine being 53 inches, the stroke 5 feet, and the number of revolutions 30 per minute, find the mean pressure of the steam to develop 600 indicated horse-power. *Ans.* 29·9.

13. Find the length of stroke in the case of a pair of horizontal marine engine cylinders, each 5' 5" diameter, mean effective pressure 20 lbs. per square inch, working at 45 revolutions per minute, and developing 905 I.H.P. *Ans.* 2' 6".

14. The two cylinders of a locomotive engine are each 17 inches in diameter, and the length of stroke is 24 inches, also the driving wheel makes 100 revolutions per minute, and the mean effective pressure of the steam is 80 lbs. Find the horse-power. *Ans.* 440·3.

* See Appendix for more recent S. & A. Questions.

15. The area of the piston of an engine is 3 square feet, the pressure of the steam is 15 lbs. per square inch above the atmosphere on admission, and the steam is cut off at ⅓ of the stroke; the crank shaft makes 40 revolutions per minute, and the length of the stroke is 3 feet. Find the I.H.P. *Ans.* Exhausting at zero-pressure = 65·9.

16. The cylinder of an engine is 3 feet 6 inches in diameter, the stroke is 5 feet, and the steam is cut off at ⅓ of the stroke. If steam be admitted into the cylinder at 45 lbs. pressure, find the work done in one stroke. *Ans.* 218,061 foot-pounds.

17. Steam enters a cylinder at 80 lbs. absolute, and is cut off at ⅓ of the stroke. The diameter of the piston is 40 inches and the length of stroke 5 feet, the number of revolutions being 50 per minute. If the back pressure be 3 lbs. absolute, find the horse-power of the engine. *Ans.* 1009 I.H.P.

18. Find the H.P. of a locomotive engine which can draw a train weighing 100 tons (including its own weight) along a level road at 30 miles per hour, the train resistance being taken at 10 lbs. per ton of load. *Ans.* 80.

19. The cylinder of a single-acting pumping engine is 72 inches in diameter with a stroke of 10 feet, and it works a pump whose plunger is 23 inches in diameter with a stroke also of 10 feet. The load is 142 lbs. per square inch of the area of the plunger. Find the mean pressure of the steam per square inch of the piston and the horse-power when the engine makes 8 strokes per minute. *Ans.* 14·49 lbs. H.P. = 143.

20. An engine is competent to raise 70 millions of pounds through one foot by the burning of 112 lbs. of coal; how many pounds of coal does it consume per horse-power per hour? *Ans.* 3·17 lbs.

21. An engine develops 250 I.H.P., and its boilers require 9 tons of coal every 24 hours. Find the consumption per horse-power per hour. *Ans.* 3·36 lbs.

22. A pair of marine screw engines have a mean effective pressure in each cylinder of 10·7 lbs. per square inch, the stroke is 45 inches, the revolutions 45 per minute, and coal is consumed at the rate of 32 cwts. per hour, or 2·26 lbs. per I.H.P. per hour. What is the diameter of each cylinder? *Ans.* 96 inches.

23. Taking steam at 45 lbs. pressure above that of the atmosphere (which is taken at 15 lbs.), sketch three diagrams showing the amounts of work obtained from a given weight of steam—(1) When used in an engine without expansion or condensation; (2) When the steam is cut off at half-stroke, but not condensed; (3) When the steam is cut off at half-stroke with condensation. (S. and A. Exam. 1890.)

24. The diameter of a steam cylinder is 24 inches, the number of revolutions = 30, and the mean effective pressure of the steam = 35 lbs. What should be the length of stroke in order that the H.P. may be 50? (S. and A. Exam. 1890.) *Ans.* 1·73 feet.

25. The piston rod of a steam cylinder and the piston rod of a blowing cylinder are each connected to the opposite ends of a working beam. The steam cylinder is 55 inches in diameter, with a stroke of 13 feet, and the blowing cylinder is 144 inches in diameter, with a stroke of 12 feet; sketch the arrangement. What pressure in the steam cylinder will balance an air pressure of 3 lbs. on the square inch above the atmosphere in the blowing cylinder? (S. and A. Exam. 1890.) *Ans.* 19 lbs. per square inch, nearly.

26. What diameter of cylinder will be required to develop 50 horse power in a non-condensing engine which has a stroke of 4 feet, and makes 45 revolutions per minute when working with a mean effective pressure of 30 lbs. above the atmosphere? $\left(\text{Take } \pi = \frac{22}{7}\right)$. (S. & A. Exam., 1893.) *Ans.* 13·9 inches.

LECTURE XVIII.

CONTENTS.—The Difference between Newcomen's Atmospheric Engine and Watt's Single-acting Engine—The Difference between a Condensing and a Non-condensing Engine—The Difference between a Single-acting and a Double-acting Engine.

WE now enter upon the descriptive part of our Elementary Course on "Steam and the Steam Engine," and begin by clearing up a few points of distinction between different types of engines.

The following questions naturally occur to students when commencing a study of the steam engine :—

(1) What is the difference between Newcomen's Atmospheric Engine and Watt's Single-acting Engine?

(2) What is the difference between a Condensing and a Non-condensing Engine?

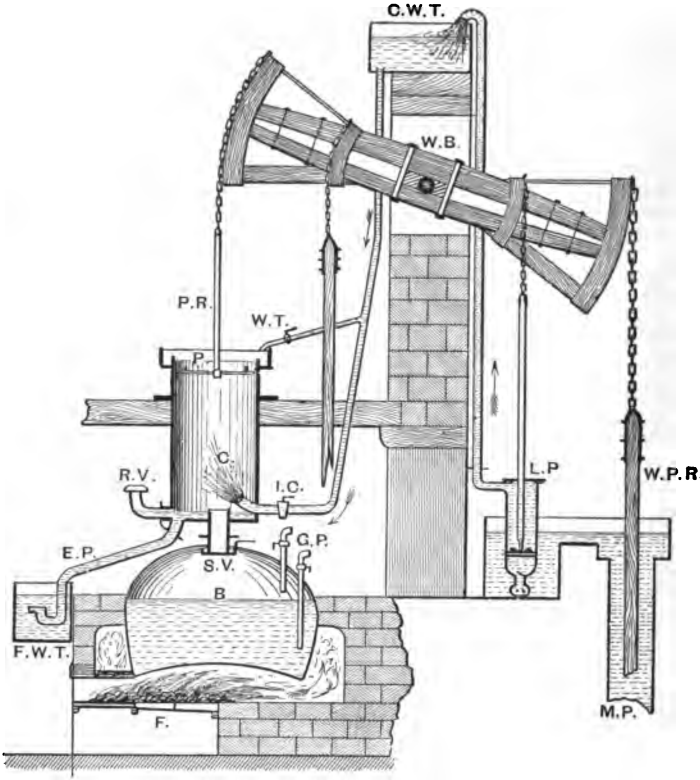
(3) What is the difference between a Single-acting and a Double-acting Engine?

(4) What is the difference between a Simple Expansion, a Compound, a Triple Expansion, and a Quadruple Expansion Engine?

We shall endeavour in this Lecture to answer the first three of these questions, and devote the next Lecture to the fourth question.

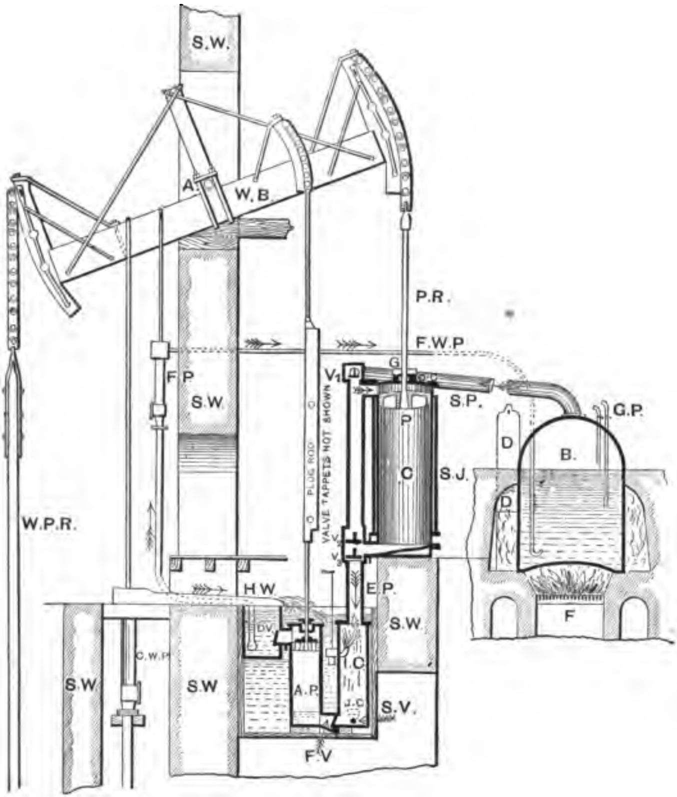
ANSWER TO QUESTION (1).—The various points of difference in the mechanical arrangement of the parts between *Newcomen's Atmospheric* engine and *Watt's Single-acting* engine will be best understood by comparing the two following figures and the indexes to parts. The chief difference, however, consists in the manner by which the steam is applied and condensed.

In Newcomen's engine, steam is admitted direct from the boiler, B, through the steam valve, S V, until it fills the cylinder, C, with steam at boiler pressure. A jet of cold water is then let into the cylinder through the injection cock, I C, which creates a partial vacuum, and permits the pressure of the atmosphere to act directly on the *uncovered* piston, P, and to force it down to the bottom of the cylinder—the piston, P, being attached to one end of the wooden beam, W B, by the piston rod, P R, and a chain, while the other end of the beam is connected by a chain to the



NEWCOMEN'S ATMOSPHERIC ENGINE, 1712.

F	for	Furnace.
B	,,	Boiler.
G P	,,	Gauge pipes.
S V	,,	Steam valve.
C	,,	Cylinder.
P	,,	Piston.
P R	,,	Piston rod.
W B	,,	Wooden beam.
W P R	,,	Weighted pump rod.
M P	for	Mine pump.
L P	,,	Lift pump.
C W T	,,	Cold-water tank.
W T	,,	Water tap to top of piston.
I C	,,	Injection cock.
R V	,,	Relief or snifting valve.
E P	,,	Eduction pipe.
F W T	,,	Feed-water tank.



WATT'S SINGLE-ACTING ENGINE, 1769.

F	for	Furnace.
D	,,	Damper.
B	,,	Boiler.
F W P	,,	Feed water pipe.
G P	,,	Gauge pipes.
S P	,,	Steam pipe.
V_1	,,	Steam valve.
V_2	,,	Equilibrium valve.
V_3	,,	Exhaust valve.
C	,,	Cylinder.
S J	,,	Steam jacket.
C C	,,	Cylinder cover.
G	,,	Gland and stuffing box.
P	,,	Piston.
P R	,,	Piston rod.
W B	for	Wooden beam.
A	,,	Axis.
W P R	,,	Weighted pump rod down to bottom of mine.
E P	,,	Exhaust pipe.
J C	,,	Jet condenser.
I C	,,	Injection cock.
C W P	,,	Cold-water pump.
A P	,,	Air pump.
S V	,,	Snifting valve.
F V	,,	Foot valve.
D V	,,	Delivery valve.
H W	,,	Hot well.
F P	,,	Feed pump.
S W	,,	Stone work.

weighted pump rod, W P R, leading down to the pump bucket in the mine pump, M P. The forcing down of the piston on the one side naturally elevates the mine-pump bucket with a quantity of water at each stroke. The return, or up stroke, of the piston is performed entirely by gravity, since the pump rod, &c., on the one side of the beam, being considerably heavier than the piston, &c., on the other side, overbalance the piston, &c. We therefore see that in this old and now discarded form of steam engine, the pressure and elastic force of the steam were *not* taken advantage of in working the engine, for the steam was *only* employed to produce a vacuum. The waste of steam through initial condensation, due to its entering a cold unprotected cylinder, was very great.

In Watt's Single-acting engine the method of attaching the piston and the pump rod to the beam was similar to that adopted by Newcomen, but there was a considerable improvement in his manner of applying and of condensing the steam. The cylinder was protected by a steam jacket all round it, from top to bottom, to keep it warm. The pressure and the elastic force of the steam *were* employed in forcing down the piston in addition to the atmospheric pressure, and the steam was condensed in a separate vessel, J C, termed by him the "jet condenser."

The action will be easily understood from the following instructions as to

How to Start Watt's Single-acting Engine:—

First.—Blow through the cylinder, C, and condenser, J C, by opening all the valves, V_1, V_2, V_3. This permits steam from the boiler, B, to expel the air from the cylinder, steam passages, and condenser.

Second.—Shut valve, V_2, and open the injection cock, I C. This creates a vacuum *below* the piston by condensing the steam in the condenser and cylinder, and at the same time it permits the steam from the boiler to force the piston down to the bottom of the cylinder.

Third.—Close valves, V_1 and V_3, and open V_2. This shuts off the boiler and the condenser connections from the cylinder, and simply allows the steam which had forced down the piston to pass (through valve V_2) underneath it, so as to create an equal steam pressure on each side of the piston, when the weighted pump rod, &c., W P R, brings the piston to the top of the cylinder.

The *second* and *third* operations are performed automatically whenever the engine has got fairly started, and the air pump, A P, clears the condenser of aqueous vapour and water so as to keep up the vacuum.

ANSWER TO QUESTION (2).—*A Condensing Engine* is one in which

the steam (after acting upon the piston, and forcing it from the beginning to the end of a stroke) exhausts into a separate chamber, and there becomes condensed into water, whereas, in a *Non-condensing Engine*, it exhausts directly into the atmosphere, or into a receiver where the pressure is greater than that of the atmosphere.

In a condensing engine, the more rapid and perfect the transformation of the exhaust steam into water, the better will be the vacuum on the side of the piston from which the steam is exhausting, and consequently the less will be the back pressure. In the case of a non-condensing engine, the back pressure can never be less than the atmospheric pressure at the time, however free the exhaust; and, when exhausting into a receiver, the back pressure will be inversely as the volume of the receiver.

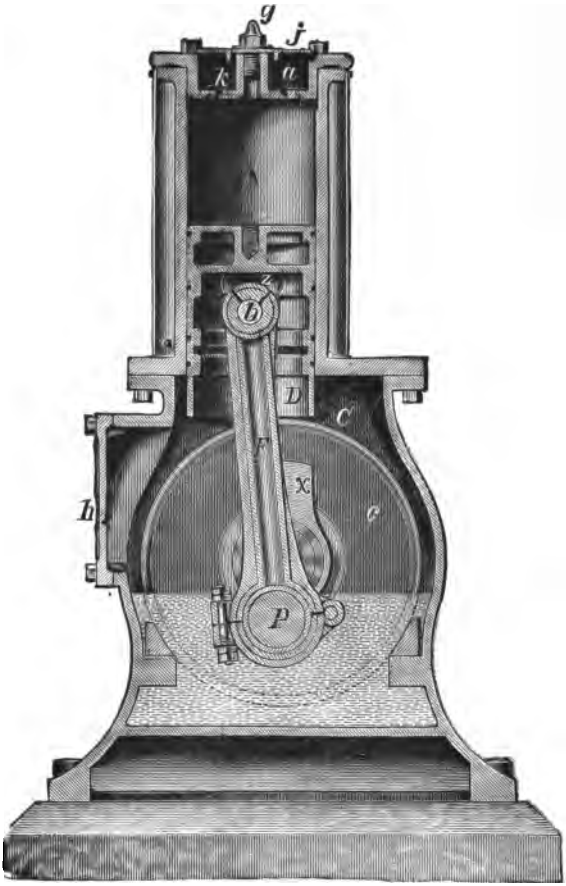
Watt's single-acting and double-acting engines, illustrated in this Lecture, are examples of old types of condensing engines, and the low-pressure cylinder of the s.s. *St. Rognvald's* compound engines is an example of a modern one. The working model illustrated in Lecture XIV., and an ordinary locomotive engine, are examples of double-acting non-condensing engines, while the Westinghouse engine (see next figure) is a single-acting one, each of them exhausting directly into the atmosphere. The high-pressure cylinder of the s.s. *St. Rognvald's* engines affords an example of a modern double-acting non-condensing engine exhausting into a receiver, where the back pressure is several pounds above the atmospheric pressure.

Answer to Question (3).—*A Single-acting Engine* is one in which steam pressure is applied to *one* side of the piston only, while a *Double-acting Engine* is one in which steam is applied to each end alternately, for the purpose of forcing it from the beginning to the end of a stroke.

Both single-acting and double-acting engines are made either of the condensing or the non-condensing type. Watt's single-acting engine, illustrated by the last figure, is an example of the old and now obsolete type of condensing single-acting engine, whereas the Westinghouse fast-speed engine, illustrated in the following figure,* is an example of a non-condensing single-acting engine, much used at the present day for the purpose of driving dynamos, mill-rolls,

* There are two single-acting cylinders, with a piston valve between them, which admits steam alternately to each cylinder. The pressure on the crank pins is always in one direction, and the speed varies from 300 revolutions per minute in the larger engines to 800 revolutions in the smaller ones. The crank is kept thoroughly lubricated by working in the oil bath, C, and the oil flows up the centre of the connecting rod to lubricate the piston pin, *b*.

fans, and special machines, where a uniform high speed is required at a particular spot, and where large floor space cannot be afforded.



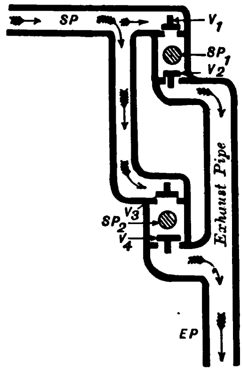
THE WESTINGHOUSE FAST SPEED SINGLE-ACTING ENGINE AS MADE BY MESSRS. ALLEY AND MACLELLAN, GLASGOW, 1888.

CROSS SECTION THROUGH ONE CYLINDER.

INDEX TO PARTS.

A for Cylinder.	P for Crank pin.
J ,, Cylinder cover.	*x* ,, Crank balance weight.
D ,, Cylinder piston.	C ,, Oil chamber.
F ,, Hollow connecting rod.	*h* ,, Hand hole.

As an example of the first successful double-acting engine, we herewith illustrate Watt's engine patented in 1784 (see p. 172). The student will understand the general arrangement by comparing the drawing with the index to parts; but in order that he may thoroughly understand the points to which we wish here particularly to draw his attention, we give a cross section of the steam and exhaust pipes, showing how the steam enters and leaves the top steam port, SP_1, and the bottom steam port, SP_2. It will be observed that there are two steam valves, V_1 and V_3, and two exhaust valves, V_2 and V_4; also, that all the four valves are automatically opened and shut at the proper times by their respective levers. These levers are actuated by projecting pins fixed to the tappet rod, T R, which is moved up and down by the metal beam, M B. The two steam valves, V_1 and V_3, open the communication between the steam pipe, S P, and their respective steam ports, SP_1 and SP_2, leading to the top and to the bottom of the cylinder. The two exhaust valves, V_2 and V_4, open communication between the top and bottom of the cylinder respectively, and the exhaust pipe leading to the condenser.



SIDE VIEW OF STEAM AND EXHAUST PIPES FOR WATT'S DOUBLE-ACTING ENGINE.

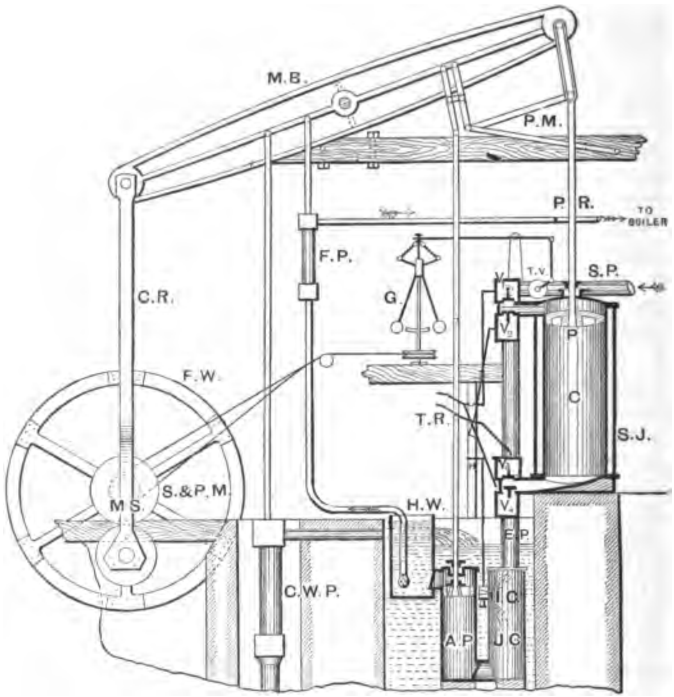
How to Start Watt's Double-acting Engine :—

First.—Blow through, so as to clear the cylinder, exhaust pipes, and condenser of air by opening all the valves, V_1, V_2, V_3, V_4.

Second.—Suppose the piston to be at the top of the cylinder, shut valves, V_2 and V_3, and open the injection cock, I C. This admits a jet of cold water into the condenser, and, therefore, condenses the steam below the piston, while, at the same time, valves, V_1 and V_4, being open, the steam from the boiler presses the piston downwards.

Third.—When the piston reaches the bottom of its stroke, shut valves, V_1 and V_4, and open valves, V_2 and V_3. This permits steam to enter the bottom of the cylinder from the boiler, and at the same time to exhaust from above the piston into the condenser.

The *second* and *third* operations are automatically performed by the tappet rod and levers as soon as the engine gets fairly under way.



Watt's Double-acting Engine, 1784.

S P	for	Steam pipe.
T V	,,	Throttle valve.
G	,,	Governor.
V_1, V_3	,,	Steam valves connected by a pipe.
V_2, V_4,	,,	Exhaust valves also connected by a pipe.
T R	,,	Tappet (or plug) rod.
C	,,	Cylinder.
S J	,,	Steam jacket.
E P	,,	Exhaust pipe.
J C	,,	Jet condenser (separate).
I C	,,	Injection cock.
H	for	Handle.
A P	,,	Air pump.
H W	,,	Hot well.
F P	,,	Feed pump.
C W P	,,	Cold-water pump.
P	,,	Piston.
P R	,,	Piston rod.
P M	,,	Parallel motion.
M B	,,	Metal beam.
C R	,,	Connecting rod.
S & P M	,,	Sun and planet motion.
M S	,,	Main shaft.
F W	,,	Fly-wheel.

LECTURE XVIII.—QUESTIONS.*

1. Explain the difference in the method of applying steam to Newcomen's Atmospheric Engine and to Watt's Single-acting Engine.

2. Make an outline sketch of the cylinder, piston, and valves connected therewith, in Newcomen's engine; and by the side of it make a second drawing of the cylinder, piston, and valves, as altered by Watt. State briefly the nature of these alterations, and mention the additional parts necessary for the working of Watt's engine, but not shown in your drawing.

3. Sketch a vertical section through the cylinder and piston of Newcomen's pumping engine. Where was the cold water for condensation admitted? What was the object of the snifting valve, and where was it placed? How was the condensing water got rid of, and prevented from returning into the cylinder? (S. and A. Exams., 1888, and similar one in 1889.)

4. Explain, with a sketch, Watt's invention of a separate condenser and air pump, as applied to a single acting steam engine? State the several improvements effected by Watt on Newcomen's engine.

5. What is the principle of the single-acting engine? Draw an outline section through the cylinder and valves, &c. Name the valves, and explain their action, also the order of opening and shutting them when starting the engine.

6. In improving the old atmospheric engine, Watt laid down the rule that the cylinder in which the steam did its work should be kept as hot as the steam which entered it. What special provisions did he make for carrying out this rule? Explain your answer by referring to such sketches as may be required.

7. Name the three principal valves connected with the steam cylinder of a single-acting pumping engine. State which are opened and which closed—(1) when the piston is at the top of the cylinder and beginning to descend; (2) when the piston is at the bottom of the cylinder and beginning to ascend.

8. What is the difference between a condensing and a non-condensing engine?

9. What is the difference between a *single-* and a *double-*acting engine? For what kind of work are single-acting condensing engines commonly used? Why is it the practice to employ three separate valves for distributing the steam in such an engine when *one* valve, properly constructed, will suffice in a *double-*acting engine? Name the valves, and mention the particular purpose for which each is required. (S. and A. Exam., 1888.)

10. Describe, with sketches, the alterations made by Watt in order to convert a single-acting into a double-acting engine. (S. and A. Exam., 1889.) What is the object of the equilibrium valve in a single-acting engine? During what portion of the stroke is this valve open?

11. In adapting the steam engine for driving machinery, Watt employed a steam cylinder with four valves for distributing the steam. Sketch a section through the cylinder of an engine of this kind, showing the valves, together with the steam and exhaust passages. Mark the valves by letters, and mention the order in which they are respectively opened and closed. (S. and A. Exam., 1887.)

12. For what kind of work are single-acting non-condensing engines used at the present day? Give a free-hand sketch through the cylinder and crank of such an engine, with an "index to parts," using the first letter of the word or words to indicate the parts. What advantages are claimed for such engines when running at a very high speed, and why?

* See Appendix for other Historical Questions.

LECTURE XIX.

CONTENTS.—The Differences between a Simple Expansion, a Compound, a Triple Expansion, and a Quadruple Expansion Engine—Reasons for the Increase of Economy obtained by using High-pressure Steam and Multiple Expansion.

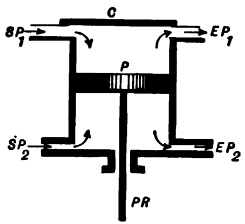
1. A *Simple Expansion Engine* is one in which the steam does work in a cylinder by expansion, and then exhausts directly into the atmosphere or into a condenser. (See first figure next page.)

There may be one or two or more cylinders connected to one crank shaft, each cylinder receiving steam direct from a boiler or boilers. Each cylinder, with its necessary parts, forms a complete simple expansion engine.

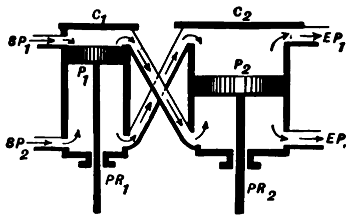
2. A *Compound Engine* is one in which the steam, after having done a certain amount of work in a high-pressure cylinder, exhausts into a larger low-pressure cylinder, where it does further work; and from this latter it exhausts into the air (if of the non-condensing compound type), or into a condenser (if of the condensing type). Or, there may be one high-pressure cylinder exhausting into two low-pressure cylinders, or two high-pressure cylinders exhausting into one or into two low-pressure cylinders. The combinations may be varied to suit circumstances, but the principle of the compound action remains the same—viz., steam direct from the boiler doing work in one or more small cylinders, and then giving out further work in one or more larger cylinders before exhausting into the air or into a condenser. The object is to split up the fall in temperature of the steam between that due to the boiler pressure and the final exhaust pressure into *two* stages, instead of effecting it at one stage, as in the simple expansion engine.

3. A *Triple Expansion Engine* is one in which the steam gives forth work in three successive cylinders, or sets of cylinders, before finally exhausting into the air or into a condenser. Here the fall in temperature between that corresponding to the boiler pressure and the final exhaust pressure is split up into *three* stages.

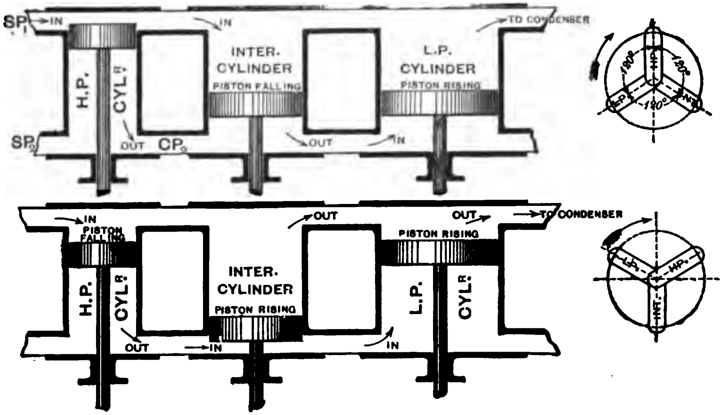
4. A *Quadruple Expansion Engine* is one in which the steam gives out work in four successive cylinders, or sets of cylinders,



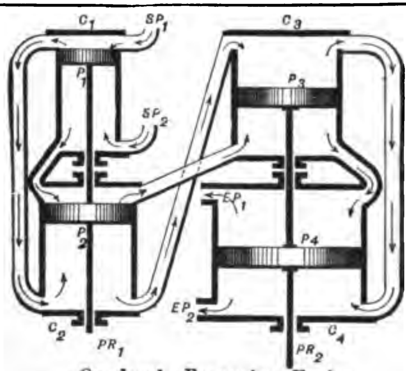
Simple Expansion Engine.



Compound Engine
2 Cranks at Right Angles.



Triple Expansion Engine. 3 *Cranks at* 120° *apart.*



Quadruple Expansion Engine
2 Cranks at Right Angles.

before finally exhausting into the air or into a condenser. Here the fall in temperature between that corresponding to the boiler pressure and the final exhaust pressure is split up into *four* stages.

There is a great variety of ways in which the cylinders or sets of cylinders may be arranged; but we have sketched these four types of engines in the last set of figures in what appears to be the most common and simple arrangement, without attempting to illustrate the valve gears by which the steam is admitted to, and exhausted from, the cylinders. The figures must, therefore, be considered merely as illustrating the difference, *in principle*, between the various types, and not as representing exact working drawings.

Referring to the four figures, we see that C_1, C_2, C_3, C_4 indicate the various cylinders; P_1, P_2, P_3, P_4, the pistons; PR_1, PR_2, PR_3, the piston rods; SP_1, SP_2, the steam ports leading from the boiler to the first cylinder; EP_1, EP_2, the exhaust pipes leading from the last or low-pressure cylinder to the air or to the condenser, according as the engine is of the non-condensing or condensing type. The other intermediate steam and exhaust pipes, along with the arrows, clearly indicate where the steam enters and exhausts from each of the other cylinders. The keen competition amongst shipowners has had the effect of stimulating engineers to produce marine engines which should develop the required horse-power with less coal and occupy less space; hence, the primary cause for the changes from the simple expansion to the compound, to the triple, and, finally, to the present, the quadruple expansion type, with a gradual increase of pressure prior to and leading up to each change.

From the commencement of steam navigation until about 1868, the simple condensing engine was universally used, with a slow but constant increase of pressure from 3 lbs. or 4 lbs. above the atmosphere to 30 lbs., and a corresponding decrease in the consumption of coal from 10 lbs. per hour per indicated horse-power to 4 lbs. These simple condensing engines, in many instances, occupied more than double the space that quadruple engines, of the same power, at the present day occupy. After the successful introduction of the compound type, about twenty years ago, by Messrs. Randolph & Elder, of Govan, the pressure gradually rose to 90 lbs. or 100 lbs., with an average consumption of 2 lbs. to 3 lbs. of coal, until 1881, when Mr. A. C. Kirk, of Messrs. Robert Napier & Sons, of Glasgow, produced the triple expansion engines for the s.s. *Aberdeen*, using steam of 125 lbs. Since that date until 1886, the pressure rose with triple expansion to 150 lbs., and a decrease in the consump-

tion to $1\frac{1}{2}$ lb. of coal, when Messrs. Rankin & Blackmore, of Greenock, constructed the engines and boilers for the steam yacht *Rionnag-na-Mara*, using steam of 160 lbs., with a mean consumption at sea of 1·43 lb. of average coal. Now pressures of 180 lbs. are becoming common, and no doubt the average consumption will soon be reduced to $1\frac{1}{4}$ lb. of coal per hour per indicated horse-power.

The student will, however, naturally ask for the reasons for this increased economy with higher pressures, and also why it can be better effected with two, three, or four stages of expansion than with what, at first sight, might seem simpler and better—viz., *one* stage, as in the simple expansion engine. If he will refer back to Lectures IX., X., and the Table, p. 107, he will see that to raise 1 lb. of water from 32° F. to 212° F., and to convert it into steam at atmospheric pressure, requires 1146 units of heat; whereas it only takes 1191 units to raise it from 32° F. to 358° F., and to produce steam of 150 lbs. per square inch, or merely the addition of 45 more units of heat.

$$\text{Consequently, as } 1146 : 1191 :: 100 : x; \quad \therefore x = 4.$$

or, only about 4 per cent. more coal will be required to produce steam of 150 lbs. pressure than would be required to generate steam of atmospheric pressure. Again, the work got out of a pound of steam depends directly on the difference of temperature between the pressure at which it enters and exhausts from the engine.* Suppose, then, the temperature of the exhaust to be 100° F., we see that, with a simple condensing engine using steam at atmospheric pressure, the fall of temperature ranges from 212° to 100°, or through 112°, whereas with, say, a triple expansion engine using steam of 150 lbs. pressure, the fall in temperature ranges from 358° to 100°, or through 258° F. Without going into the calculation, which must be left for the more advanced student, we may here state generally that, by adopting the higher pressure, we should get more than double the work out of the same weight of steam by using it at 150 lbs. pressure instead of at the atmospheric pressure; and, as we have just seen, we should only require to burn about 4 per cent. more coal; besides, with a very great reduction in the size of the engine, it would suffice to develop the same horse-power.

* *The Engineer* of August 24, 1888, p. 162, in reviewing the third edition of the author's senior *Text-book on Steam and Steam Engines*, criticizes this statement, and says that "it will probably soon be recognized that the great actual efficiency of high-pressure steam is due to the fact that at the higher pressures the work represented by the expanding steam is more nearly proportional to the units of heat used than at the lower pressures."

The reasons generally given why this economy cannot be effected in one cylinder are, that at every stroke the inside of the cylinder would be put into direct communication with the condenser, and its temperature thereby lowered to nearly the same temperature as the condenser; consequently, if fresh steam of a high temperature (say, that corresponding to 150 lbs. pressure, or 358° F.) were introduced into a cylinder of little over 100° F., a very large quantity of the steam would be immediately condensed, and we should have the same evil—only to a less degree—as that which occurred in the case of Newcomen's engine, referred to in the last Lecture. If we, however, split up the fall in temperature of the steam into three or four stages, by causing it to do work in three or four successive cylinders—say, a fall of from 358° to 300° in the first, from 300° to 250° in the second, from 250° to 212° in the third, and from 212° to 100° in the fourth—then we see that it is only the last cylinder which comes into direct communication with the condenser. The range of temperature in the first cylinder is only 50°, so that the amount of initial condensation will be very considerably reduced. Further, if we attempted to develop the necessary power in one or more long simple expansion cylinders, the cut off would have to be very early, to permit of the expansion reducing the temperature from 358° to 100°. The range of pressure would also be very great, and all the parts would have to be made sufficiently strong to withstand the high initial pressure. This would necessitate an inconveniently long stroke and a heavier engine to develop the same power.

Engineers have, in all probability, not reached the limit of pressure that can be safely and economically used; but the problem is becoming more and more difficult, whilst, for many reasons, the gain in coal, space, and first cost is proportionally less.

LECTURE XIX.—QUESTIONS.

1. Define the difference between a simple expansion engine, a compound, a triple, and a quadruple expansion engine.

2. Sketch the general arrangement of cylinders for these four types of engines, and trace the directions followed by the steam without attempting to show the actual positions of valves used.

3. Give reasons for the increased economy derived from using steam of high pressure and multiple expansion in several cylinders.

4. Why have engineers preferred to adopt compound, triple, or quadruple expansion cylinders instead of single cylinders, each receiving steam of high pressure, and exhausting into the air or into a condenser?

5. The cylinders of the engines in the s.s. *Aberdeen* are 30", 45", and 70" diameter respectively, by 4' 6" stroke. Find the areas and the volumes of each cylinder, and the ratio of the area of the low-pressure cylinder to the high and to the intermediate. Suppose the steam to be cut off at half stroke in each cylinder, by how many times does it expand? *Ans.* The areas of the three cylinders are respectively 706·9, 1590, and 3848·5 square inches. The volumes are respectively 38,173, 85,860, and 207,819 cubic inches. The steam expands 10·8 times.

6. Explain the difference between—(1) A simple non-condensing engine; (2) A compound double cylinder condensing engine; (3) A triple expansion engine; and mention some of the advantages of each type of engine. (S. & A. Exam., 1894.)

7. What is the difference between a simple non-condensing engine, a condensing engine, and a compound non-condensing engine? Describe, with a sectional sketch, the arrangement and action of Hornblower's compound engine. You may take either the single or double acting engine. (S. & A. Exam., 1893.) (For description of Hornblower's engine see the Author's "Text Book on Steam and Steam Engines," p. 18.)

8. Explain the difference between a simple non-condensing engine, a condensing engine, and a compound non-condensing engine. Give outline sketches of the general arrangement in a horizontal engine of each of the three classes. (S. & A. Exam. 1896.)

LECTURE XX.

CONTENTS.—General Description and Detailed Index to Parts of the s.s. *St. Rognvald's* Engines.

HAVING described the main features of distinction between condensing and non-condensing, single-acting and double-acting, simple, compound, triple, and quadruple expansion steam engines, we are now in a position to explain in detail a modern engine. Of the great variety at our disposal, we prefer to select a compound marine engine; because, if the student masters the construction and action of this type, he will have very little difficulty in understanding any ordinary land engine, simple or compound. Greater ingenuity has been displayed by the designers and makers of marine engines than by any other class of engine designers and makers, in perfecting and arranging details as well as in economizing fuel—from the fact, that the space and position allotted to the marine engine are limited, and every ton of coal saved means a ton of freight earned as well as a saving of expense in firing, and, in many traders, of time in stopping to coal at different ports.

The following sectional front and side elevations, and plan, drawn to a scale of $\frac{1}{30}$th, illustrate the engines of the s.s. *St. Rognvald*, one of the most successful steamers belonging to the North of Scotland, Orkney, and Shetland Steam Shipping Company, designed and made by Messrs. Hall, Russell, & Co., Aberdeen. In the following Lectures we shall illustrate and describe a number of the most important details of these engines as well as the boilers, in order that the student may have a comprehensive and accurate account of one complete set of engines, in preference to a mixture of a variety of different types. Before reading over the following general description, the student should carefully compare the "index to parts" with the drawings, in order to be the better able to understand the explanation.

General Description of the s.s. "St. Rognvald's" Engines.—The high-pressure cylinder is 36 inches diameter, and the low-pressure cylinder 70 inches diameter, both with a stroke of 4 feet.

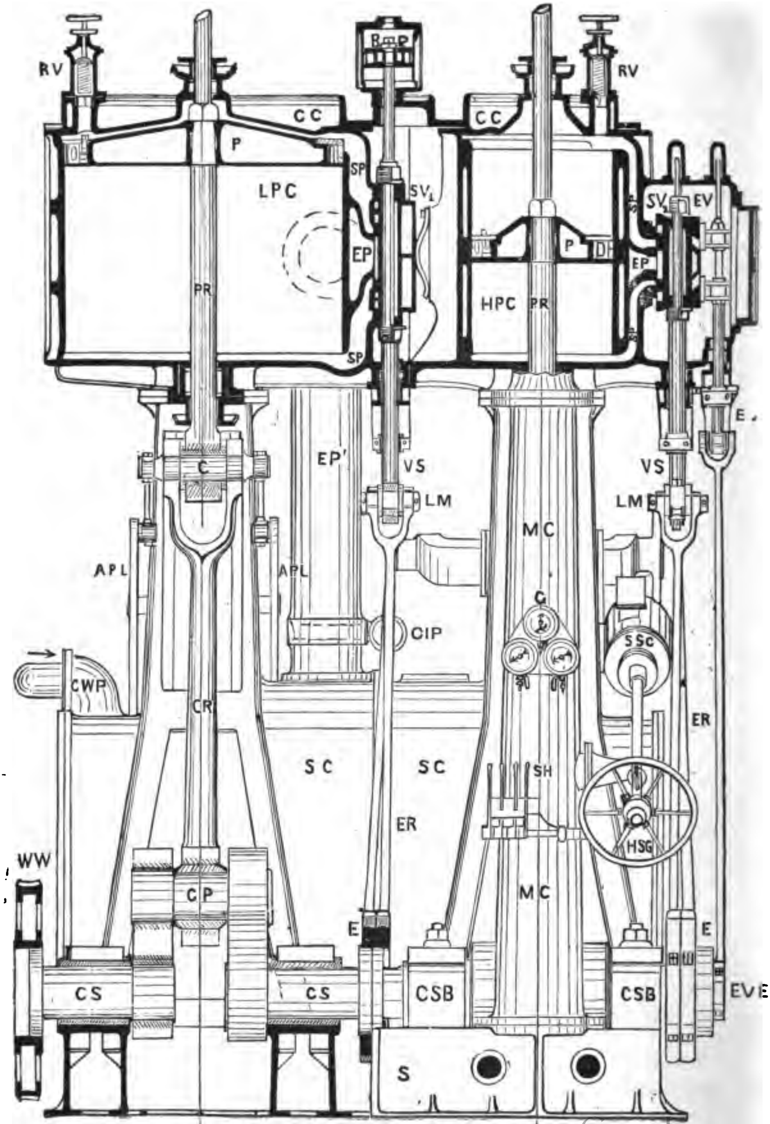
At the trial trip the engines developed as follows:—

Revolutions per minute.	Steam in lbs. per square inch.	Vacuum in inches.	Indicated Horse-power.
72	90	24	1536
70	86	24	1390
64	72	24·5	988

Course of the Steam.—The steam enters the valve casing of the high-pressure cylinder by the stop valve, S V, and throttle valve, T V, and is then admitted to that cylinder by the slide valve, S V_2. Full steam is admitted to the cylinder for a portion of the stroke, until the expansion valve cuts off the supply. After this point, the work of moving forward the piston is performed by the expansive force of the steam, and the steam falls in pressure and temperature from this point to the end of the stroke. At the end of the stroke the steam is exhausted through a belt, B, or passage, round the high-pressure cylinder (shown in the plan and side elevation), into the slide-valve casing of the low-pressure cylinder. This casing of the low-pressure cylinder, along with the exhaust passages from the high-pressure cylinder, forms the receiver of the engine, and when the steam exhausts into this receiver its pressure falls by expansion, since the volume of the receiver is greater than that of the high-pressure cylinder. This fall of pressure is an apparent source of loss to the system; but since the steam while expanding into the receiver does no work, it cannot lose heat except by radiation and conduction, which is as far as possible prevented by the lagging, and therefore if it fall in pressure it must become drier or superheated. Consequently, whilst expanding in the low-pressure cylinder, it will not be so liable to liquefaction, and will be more efficient than ordinary saturated steam, so that theoretically there should be no loss due to this receiver. The steam is admitted to the low-pressure cylinder by the double-ported slide valve, S V_1. The expansion is completed in this cylinder, and the remaining available energy given up by the steam. From the low-pressure cylinder it is discharged through the exhaust pipe, E P′, into the surface condenser, S C, and is there condensed. When condensed, it falls to the bottom of the condenser, and is pumped by the air pump, A P, from the surface condenser discharge pipe, S C, D P (see plan), and by it sent into the hot well, H, from which it is drawn off by the feed pumps, F P, and forced back into the main boilers, to be again evaporated and passed through the engine. If no leakage took place at any point, then the water originally supplied would last without any addition for a very long time.

Slide Valves.—The high-pressure cylinder is fitted with variable expansion gear, so that the point of cut off of the steam, and con-

FRONT ELEVATION.

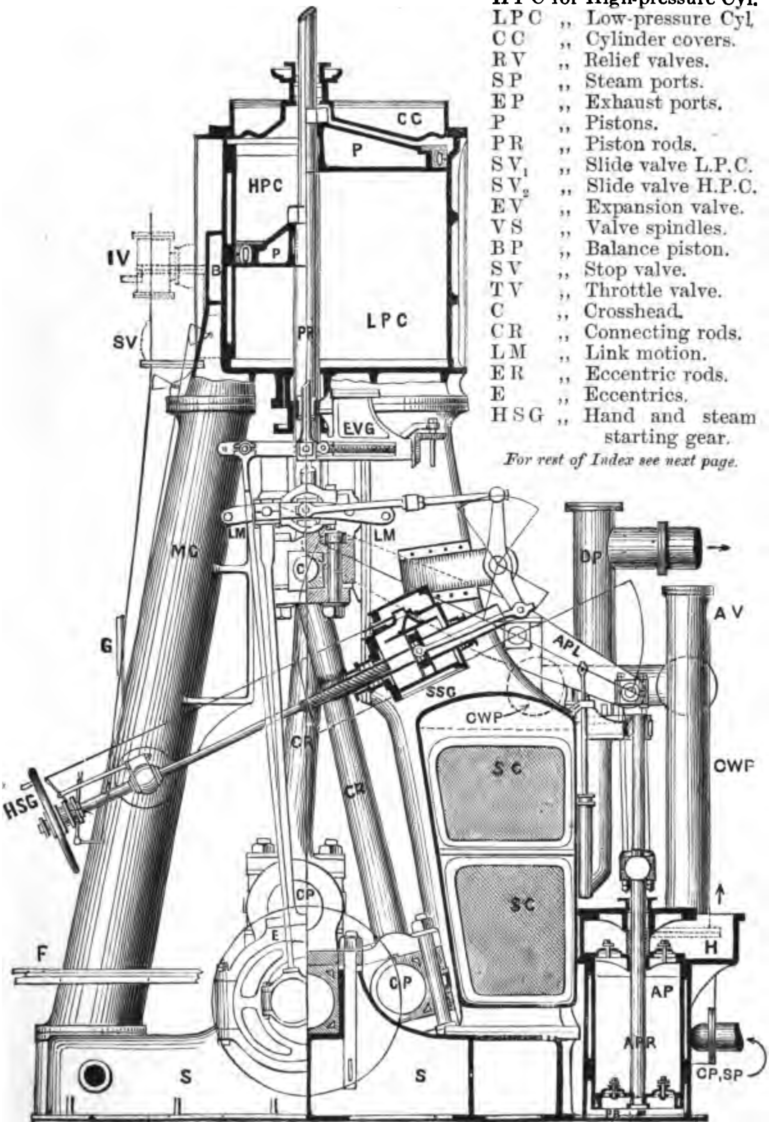


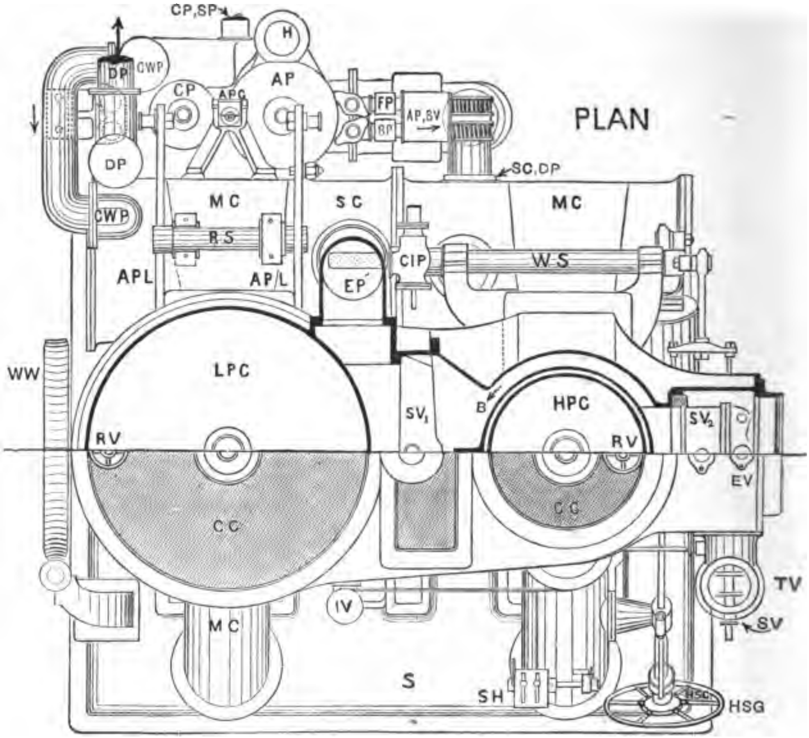
SIDE ELEVATION.

INDEX TO PARTS.

H P C for High-pressure Cyl.
L P C ,, Low-pressure Cyl.
C C ,, Cylinder covers.
R V ,, Relief valves.
S P ,, Steam ports.
E P ,, Exhaust ports.
P ,, Pistons.
P R ,, Piston rods.
SV_1 ,, Slide valve L.P.C.
SV_2 ,, Slide valve H.P.C.
E V ,, Expansion valve.
V S ,, Valve spindles.
B P ,, Balance piston.
S V ,, Stop valve.
T V ,, Throttle valve.
C ,, Crosshead.
C R ,, Connecting rods.
L M ,, Link motion.
E R ,, Eccentric rods.
E ,, Eccentrics.
H S G ,, Hand and steam starting gear.

For rest of Index see next page.





PLAN OF S.S. "ST. ROGNVALD'S" ENGINES.

INDEX TO PARTS—(*continued*).

S S G for Steam starting gear.
W S „ Wyper shaft.
E V G „ Expansion valve gear.
E V E „ Expansion valve eccentric.
S H „ Starting handles.
S „ Sole plate.
M C „ Main columns.
E P′ „ Exhaust pipe.
S C „ Surface condenser.
F „ Flooring.
C S „ Crank shaft.
C S B „ Crank-shaft bearings.
A P „ Air pump.
H „ Hot well.
A P L for Air-pump levers.
R S „ Rocking shaft.
A P R „ Air-pump rod.
A P G „ Air-pump rod guide.
P B „ Air-pump bucket.
F P, B P „ Feed and bilge pumps.
C P „ Circulating pump.
C P S P „ Circulating suction pipe.
C W P „ Circulating water pipe.
D P „ Discharge pipe.
C I P „ Common injection pipe.
G „ Gauges, steam, vacuum, and receiver.
W W „ Worm wheel for turning gear.

sequently the power, may be changed to suit circumstances. The variation of the point of cut-off is effected by means of the expansion-valve gear arrangement shown at, E V G, in the side elevation, by which the travel of the valve may be altered. In the low-pressure cylinder the weight of the slide valve, together with the valve rod, links, and eccentric rods, is supported by a small balance piston, B P, fitted to the upper end of the valve rod, so that what would otherwise cause great pressure and consequent friction between the eccentrics and their straps and other points, is considerably diminished.

Starting and Reversing Gear.—The steam-starting gear, S S G, is very simple, and is clearly shown in the side and front elevations. It consists of a small steam cylinder, which is bolted to the side of the forward condenser column, and has a trunk fitted to the back side of its piston, through which passes a small connecting rod to one end of a bent lever, keyed to the wyper shaft, W S. This lever is connected at its other extremity to the centre of the reversing link motion, L M, of the high-pressure cylinder, and another lever which is attached to the same wyper shaft, W S, is connected to the link motion of the low-pressure cylinder. The other end of the piston, which is also of the trunk form, is screwed with a very fast pitched thread to fit the screw on the round rod to which the reversing or hand-starting gear wheel, H S G, is attached. The reversing wheel is loose upon this rod when reversing the engines by aid of steam, but may be firmly attached to it by means of a clutch when it is desirable to reverse by hand only. The slide valve of the steam-starting cylinder is worked by a small hand lever and a valve rod, fixed near the back of the starting wheel, as seen by the side elevation. By pulling or pushing this small lever, the small slide valve is made to admit steam to either end of the steam-starting cylinder at pleasure, forcing the piston forward or backward, and thus the link motion, L M, of the main engines may be moved forward or backward at pleasure, and their slide valves thrown into gear with the ahead or the astern going eccentrics. In order to reverse by hand, it is only necessary to throw the clutch into gear with the reversing wheel, and to revolve the wheel, when the small trunk piston is moved directly by the action of the screw. In reversing by steam, the piston presses against this screw on the rod, and the pitch of the screw being great, it causes the rod to revolve, but the reversing wheel does not revolve since the clutch is not in gear.

Air, Circulating, Feed, and Bilge Pumps.—The air pump, A P, circulating pump, C P, feed pump, F P, and bilge pump, B P, are all worked from one crosshead attached to the outer end of

the air-pump levers, A P L, which are keyed to the rocking shaft, R S. The inner end of the levers, A P L, are attached by short links to the crosshead, C, of the low-pressure cylinder piston rod, P R (see all three views). An enlarged section and plan of the air and the circulating pumps, with a detailed description, will be given in a future Lecture. As explained above under the heading "Course of the Steam," the condensed steam, on falling to the bottom of the condenser, is drawn therefrom through the surface condenser discharge pipe, S C, D P, and the air-pump suction valve, A P, S V, by the air pump, and transferred to the hot well, H, from which it is pumped by the feed pump, F P, into the boiler; but the air which comes from the surface condenser is allowed to escape through the side of the ship by a pipe leading from the top of the hot well, H. This pipe is not shown in the drawings. A jet condenser cold-water injection pipe, C I P (see front elevation and plan), with a rose pipe on its end, is fitted to the bottom of the exhaust pipe, E P′, so that the steam may be condensed by the old method of jet-condensation, should the surface condenser or any of its auxiliary parts break down. Under ordinary circumstances, however, the double-acting circulating pump, C P, draws in cold water from the sea through the circulating pump suction pipe, C P, S P (see side elevation and plan), and forces it through the cold-water pipe, C W P, into the top of the surface condenser (see also front elevation) through the upper tier of horizontal tubes, and then back again through the lower set of tubes, and through the vertical discharge pipe, D P, out to sea again: thus keeping up a continuous circulation of cold water through all the condenser tubes, whereby the exhaust steam, as it spreads over these tubes on leaving the exhaust pipe, is condensed on their cold surface and gravitates to the bottom of the condenser.

Turning Gear.—A worm wheel, W W, is attached to the after-end of the crank shaft, C S, and a worm, driven by a small engine, gears with this wheel. This arrangement is necessary for turning the engines while the vessel is lying in port, and the worm is fitted in such a way that it may be easily and quickly thrown out of gear before the main engines are worked by steam.

Governor.—A marine-engine governor is fitted to the after bulkhead in a convenient position (not shown), and is driven by a rope from a V-grooved pulley keyed to the crank shaft just outside the worm wheel, W W. This governor actuates a valve near the throttle valve, T V, in the main steam pipe, and helps to prevent the engines racing when the ship is in a heavy sea.

Gauges.—Three circular-faced gauges, G, are shown in the front elevation, fixed to the forward front main column, M C. One of these is the steam gauge for indicating the pressure of steam in

the main steam pipe, or the initial pressure as it enters the high-pressure cylinder valve casing; another is for indicating the pressure of steam in the intermediate receiver, B, between the high and low pressure cylinders or the back pressure on the high-pressure piston; and the third is for indicating the vacuum in the condenser or the back pressure on the low-pressure piston. Each gauge is connected directly to the space wherein the pressure is to be ascertained by a small solid drawn copper pipe and cock, which is always kept open during the time that the engines are working.

Starting Handles.—Immediately below the gauges, and at a handy height for the engineer on watch, are fixed four starting handles, S H. One handle is connected to a throttle valve in the main steam pipe near the governor throttle valve, T V, so that the engineer may suddenly check the speed of the engines, or stop them, or, by partially closing this valve, work the engines at any desired speed (with the stop valve full open and the link motion in full gear) as required. The second and third handles are connected respectively to the drain cocks of the valve casing and the jacket water trap below the high-pressure cylinder, so as to free these places from any water that may accumulate there, due to priming or condensation. The pipes leading from these drain cocks are taken directly to the hot well, H, so as to economize as far as possible all the condensed steam and have it pumped back to the boiler. The fourth handle is connected to an impulse piston valve, I V, connected to the low-pressure cylinder supplied with steam direct from the donkey boiler, so that live steam may be admitted to the top or bottom of this cylinder at pleasure, for the purpose of starting the engines over the dead centres, should they not move away directly when steam is applied in the ordinary way, and for the purpose also of warming up the whole of the parts connected with that cylinder.

To Start the Engines.—First, warm up slowly and carefully every part connected with the valve casings and cylinders, and then blow through the condenser so as to clear all the spaces of air and water, by partially opening the stop valve, S V, throttle valve, T V, the drain cocks, and the impulse valve, I V, attached to low-pressure cylinder, and moving the link motion first into forward, then into back, gear. (Sometimes a special set of cocks and pipes are employed for warming up and blowing through.) Second, open the stop valve and throttle valve as fully as may be required, and move the link motion into forward gear so as to make the engines go ahead.

Lecture XX.—Questions.

1. Make a complete *free-hand* sketch of the three views of the s.s. *St. Rognvald's* engines, as given in this Lecture; attach all the index letters, write out a complete index to parts, and describe in your own words the general arrangement of the whole engine, as well as how it is started and reversed, without referring to the text-book.

2. The diameter of the high-pressure cylinder is 36", and the low-pressure cylinder 70", in the *St. Rognvald's* engines. Find the ratio of the cross areas of the two pistons. *Ans.* 1 : 3·76.

3. The diameters of the cylinders being 36" and 70", as stated in Question 2, and the stroke of each piston being 4': find the superficial area of the inside of the cylinder liners (neglecting clearance lengths and depth of pistons), and also the volume swept through by each piston. *Ans.*

4. Suppose that steam is cut off at half stroke in the high-pressure cylinder of the s.s. *St. Rognvald's* engines, what is the total ratio of expansion of the steam (neglecting clearance)? *Ans.* 7·52.

5. Steam is supplied at 90 lbs. pressure on the square inch by steam gauge to the high-pressure cylinder of the s.s. *St. Rognvald's* engines. Suppose that it is cut off at half stroke, and that the back pressure is 25 lbs. above atmospheric pressure; also, that steam is cut off at half stroke in the low-pressure cylinder, and that the back pressure is 4 lbs. absolute; how many revolutions per minute must the engines work at in order to develop 1500 I.H.P.? *Ans.* 38.

6. The cylinders of a compound engine are 25" and 45" in diameter. Find the ratio of their areas. *Ans.* 1 to 3·24.

7. The cylinders of a compound engine are 25" and 45" in diameter; with the same stroke, the mean effective pressure of steam in the smaller cylinder is 40 lbs., and in the larger cylinder 12 lbs. Which cylinder is doing most work, and by what percentage? *Ans.* The smaller cylinder; by 2·6 %.

8. What is the total ratio of expansion in a compound engine with cylinders 31" and 62" diameter, and the same stroke, when steam is cut off at half stroke in the high-pressure cylinder? *Ans.* 8 times.

9. Find the indicated horse-power of a compound engine, the cylinders being 27·5" and 48" diameter; stroke in each case 2·5'; revolutions per minute 75; the mean effective pressure in high-pressure cylinder being 37 lbs., and in low-pressure cylinder 7·35 lbs. *Ans.* 400·8.

10. Steam is admitted into the high-pressure cylinder of a compound engine at 70 lbs. by gauge, and cut off at ·4 of the stroke. The cubic capacity or volume swept through by the piston of the low-pressure cylinder being 3 times that of the high-pressure one: find the final pressure per square inch of the steam when it exhausts into the condenser. *Ans.* 11·3 lbs. absolute.

11. Sketch in section the high pressure cylinder, with slide and expansion valve, as forming part of a compound cylinder marine engine. Describe briefly the arrangement of the engine, and how the condensation of steam is effected. (S. & A. Exam., 1893.)

12. Sketch and describe the escape valve as fitted to the cylinders of a marine engine. What is the use of such a valve? Show, by a sketch, where it is fixed. (S. & A. Exam. 1896.)

LECTURE XXI.

CONTENTS.—Details of Engines—Cylinders—Cylinder Covers—Stuffing Boxes, Glands, and Packing—Relief Valves—Steam Ports—Pistons —Piston Rods and Crossheads—Connecting Rods; with Specification for Details of s.s. *St. Rognvald's* Cylinders, &c. &c.

IN this and the two following Lectures we shall enter very fully into the details of a compound marine engine, illustrating our remarks by a series of figures reduced from the working drawings of the s.s. *St. Rognvald's* engines, kindly furnished to the author by the makers, Messrs. Hall, Russell, & Co., Aberdeen, as well as by extracts from the contract specification.

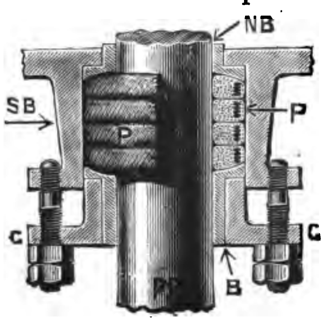
Reference should be made when required to the three figures in last Lecture.

Details of Engines—Cylinders.—Cast iron is the material universally employed for the construction of steam-engine cylinders. The inside of the cylinder barrel is frequently fitted with a thin liner, which is made of a hard close-grained material, capable of taking on a high polish and withstanding the rubbing action of the piston. If the liner becomes much worn, it may be taken out and replaced by a new one at a very small expense; or it may be re-bored, if only slightly worn. In small engines it is not usual to fit the cylinders with liners, but the metal of the cylinder barrel is made thicker than is necessary for strength at first, so that when the cylinder becomes much worn, it may be re-bored and fitted with a new piston. When the cylinder is to be steam-jacketed, a liner is now always employed, and steam is circulated round the annular space between the cylinder barrel and the liner. Cylinder liners are usually constructed of hard cast iron; but compressed steel liners, as manufactured by Sir Joseph Whitworth's patent process, have been largely employed, and have given satisfactory results. The method of fitting-in these liners will be readily understood by reference to the high-pressure cylinder of the *St. Rognvald's* engines, illustrated in the last Lecture. The interior of the cylinder barrel has a fitting strip at each end and at the middle, which projects from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch above the interior surface of the barrel itself; and these strips are bored out so as to fit exactly similar strips on the external surface of

the liner. The annular space between the liner and the cylinder barrel is therefore about 1 inch, and the hot steam from the boiler is passed round this space. The liner is usually fixed-in by an internal flange on its lower or inner end, which is sometimes recessed into a space in that end of the cylinder, and is attached to the cylinder end by screwed pins. To prevent waste of steam, it is necessary that the joints between the liner and the cylinder barrel should be steam-tight, and at the inner joint this may be effected by the use of red lead, when the liner is being fixed in its place. At the back or upper end, however, a small groove is usually bored out at the joint immediately above the fitting strip, and this groove is packed with soft rope, asbestos, or some of the other packings in general use. This packing is kept in position by a thin wrought-iron ring, which is fixed to the top of the liner. A very simple and efficient plan is to caulk a thin copper ring into a space bored out for it above the fitting strip.

Cylinder Covers.—One of the ends of a steam-engine cylinder, called the cover, is always bolted on, whilst the other is usually cast along with the cylinder barrel. It is the back or upper end which is separate from the cylinder barrel. In large engines, and all jacketed engines, this cover is made hollow, and the flat sides are connected by ribs. In small engines, it consists simply of a circular plate of metal. This cover is held down by studs, which are screwed into a flange on the cylinder barrel, and are sufficiently strong to resist the full initial pressure of the steam acting on the area of the cover. The pitch of these studs must not be too great, since it then becomes difficult to keep the joint steam-tight.

Stuffing Boxes and Gland Packings.—It is of the greatest importance that piston rods and valve spindles should be kept thoroughly steam tight without any unnecessary loss in power, and wear and tear due to friction. The stuffing boxes for holding the packing are generally cast along with the cylinder or with the cover, but in the case of the lower ones in the piston rods of large engines, they are sometimes made separate and bolted on. The following figure shows very clearly how the stuffing boxes for the piston rods and the valve spindles of the s.s. *St. Rognvald's* engines are made and packed with Bell's asbestos packing.



INDEX TO PARTS.

PR for Piston rod.
SB ,, Stuffing box.
NB ,, Neck brass.
P ,, Packing (Bell's asbestos).
G ,, Gland.
B ,, Gland brass.

Numerous devices of various kinds have from time to time been brought out with the object of providing a perfect packing for piston rods. The metallic packing in the following illustration is one of the simplest and best we have met with. As will be seen from the engravings, the metallic packing rings are inserted in the stuffing box alternately with rings of ordinary flexible packing. Each metallic ring is made in four parts, two being internal and two external, each pair forming a complete circle. On each face of the combined ring is a semicircular groove, which forms, as shown, a recess for the flexible packing. On tightening the gland down, the ordinary packing is flattened out, tending to drive the outer and inner metallic rings apart, pressing them against the piston rod and the sides of the stuffing box. The metallic packing is thus held up to the rod without undue pressure, and prevents the softer packing from being destroyed by the high-temperature-steam. It is reported of this packing that, after having been in the high-pressure cylinder of the s.s. *Alcides*, using steam of 150 lbs., and for a run of over 60,000 knots, it looked as good as when first put in.

BAIRD'S METALLIC PACKING.

Relief Valves.—Relief or escape valves, R V (see figs. in last Lecture), are usually fitted to cylinder covers and cylinder ends, and consist of simple mushroom valves loaded with springs. Their function is to allow a means of escape for the water which may collect in the cylinder, either by "priming" in the boiler, or by condensation in the cylinder. When the piston approaches the end of its stroke, it forces this water into the clearance spaces, and if there is more than sufficient water to fill them, the pressure opens the relief valves and allows it to escape.

Steam Ports.—The steam ports and passages are almost always cast along with the cylinder barrel, and in small engines the valve casing also forms part of the same casting. In large engines, however, the valve casing is bolted on. The face of the steam and exhaust ports, against which the slide valve works, is usually planed and scraped up to a true plane surface, so that it may form absolutely steam-tight contact with the valve. Sometimes a valve face of a specially hard cast iron is fixed on to the face of the steam ports (as shown in the figs., pp. 217, 219) so as to prevent excessive wear. It is generally attached by small screws, the heads of which are sunk below the flush of the valve face. In some few cases bronze valve faces have been used; but these, although forming a good surface for the valve to work against, cannot be recommended, because when so fixed the bronze warps, due to its greater co-efficient of expansion by heat.

Specification for the s.s. "St. Rognvald's"

(1) *Cylinders.**—To have one high-pressure cylinder, H P C, and one low-pressure cylinder, L P C. The high-pressure cylinder to be 36 inches in diameter, and the low-pressure cylinder 70 inches diameter, each with a stroke of 4 feet. To be made of hard close-grained cast iron, strongly ribbed and feathered on sides and on bottoms, of a minimum thickness of 1¼ inch, with relief valves, R V, and stuffing boxes fitted at top and bottom of each cylinder. The high-pressure cylinder to have a cast-iron liner, 1⅛ inch thick, fitted with a space of 1 inch between it and outside casting, the space thus formed to be used as a steam jacket if required. This jacket space to have a water trap fitted below the level of cylinder bottom, with a gauge glass at least 18 inches long, with suitable brass cocks (asbestos packed). The water from trap to be taken into hot well by a copper pipe, ¾ inch diameter, having a brass stop valve for regulating the flow of water. The cylinders and valve-casing sides to be covered with silicate of cotton, 2 inches thick, and lagged with teakwood in strips 3 inches broad, and secured by brass straps and screws. The bore of each cylinder to be made so that the packing rings of pistons shall work ¼ inch past it at each end, a recess to be formed above and below the bore ½ inch deep to allow for the cylinders being bored out. A separate valve face to be fitted to high-pressure cylinder, fastened with brass pins. The bottom piston-rod

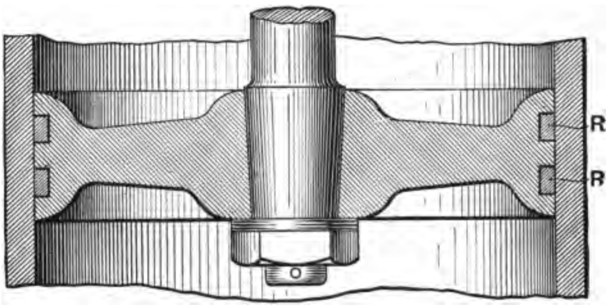
* Students should carefully compare this specification with the drawings.

stuffing boxes to be 10 inches deep, and fitted with brass neck rings, 3½ inches deep; glands to be bushed with brass, and fitted with an arrangement whereby all the nuts can be tightened up at once. The relief or escape valves to be fitted with polished cast-iron covers, with brass regulating screws, fitted with polished cast-iron hand wheels. A man hole, 15 inches diameter, to be fitted in bottom of low-pressure cylinder, and a hand hole, 8 inches diameter, in bottom of high-pressure cylinder for cleaning purposes.

(2) *Cylinder Covers* (C C).—To be of strong cast iron, 1⅜ inch thick, fitted with strong T-feathers on top, covered with wrought-iron chequered plates. Flanges to be polished, and secured to cylinders with studs and polished steel nuts. Stuffing boxes to be fitted, 7 inches deep, with saucers for catching the waste oil from the tail rods.

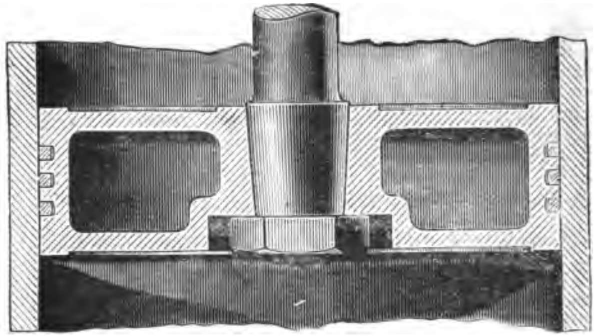
(3) *Packing Glands*.—All glands about the engines and boilers which are not of brass to be bushed with brass, and to have brass neck rings. The piston-rod and valve-spindle glands to have saucers cast on them for catching oil.

Pistons.—There are an immense variety of patent pistons, each having some particular feature claimed for it by the inventor

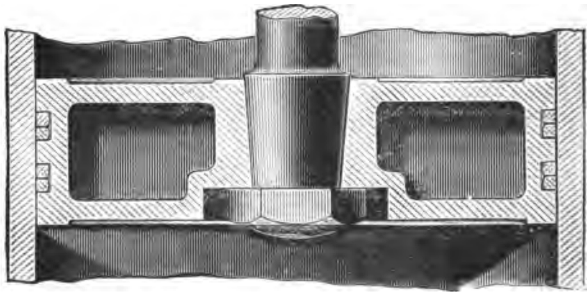


LOCOMOTIVE PISTON WITH RAMSBOTTOM RINGS,

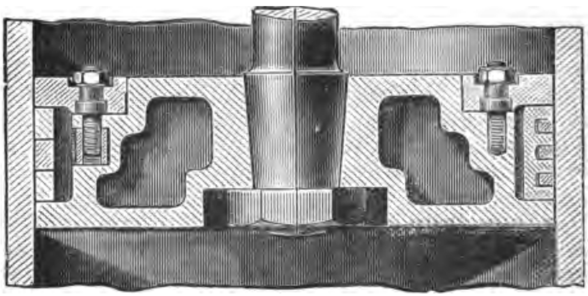
We have only space, however, to illustrate a few forms which have proved successful in practice. A good piston, besides having sufficient strength to withstand the pressure to which it is subjected, should be absolutely steam-tight, and should exert a uniform pressure all round its circumference; but this pressure should not be so great as to create excessive friction between it and the cylinder. The simplest form of piston is that used in locomotives and small engines. This piston is kept steam-tight by two or three (hard cold blast grey Scotch cast iron) packing rings R R, which are known as Ramsbottom's rings. These rings are turned slightly larger in diameter than the bore of the cylinder, and are afterwards cut across, so that they may be compressed into it. They are fitted into recesses turned in the piston, and the cut joints of the rings are set at opposite sides of it. This form of piston works very well for small cylinders, and also for



BOX SECTION OF PISTON WITH THE USUAL ARRANGEMENT OF THREE RINGS.

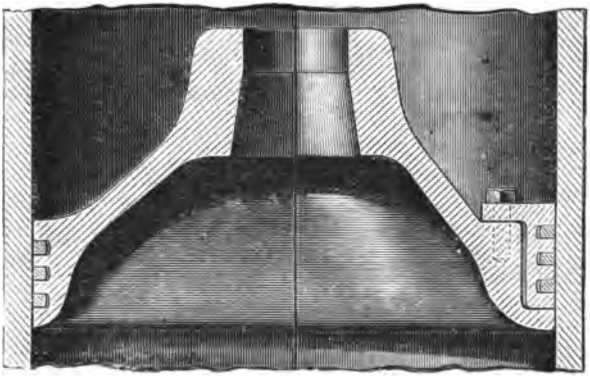


BOX SECTION OF PISTON WITH A PARTICULAR ARRANGEMENT OF FOUR RINGS.

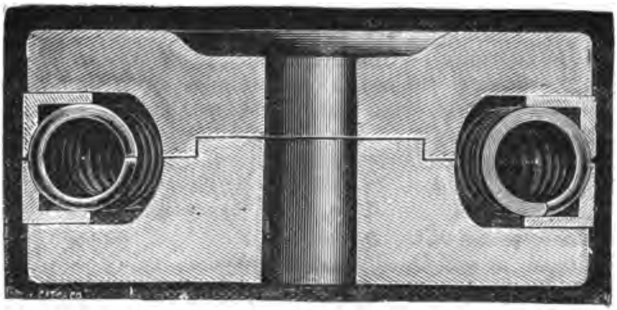


TWO METHODS OF APPLYING THE PACKING RINGS TO PISTONS WITH JUNK COVERS.

The first four of the above figures and one for an air-pump bucket have kindly been presented by Messrs. P. R. Jackson & Co., of the Salford Rolling Mills, Manchester, from their copyright book.



TWO METHODS OF APPLYING THE PACKING RINGS TO MARINE ENGINE PISTON.

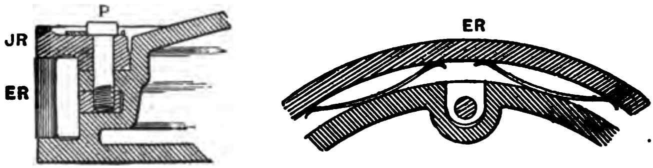


THE LANCASTER SPIRAL-SPRING PISTON.

the high pressure cylinders of large land and marine engines Engine pistons above 20 inches diameter are, however, frequently constructed hollow, or on the box pattern, as shown by three of the preceding figures. Some very large marine engine pistons for fast-running engines have been made of cast steel with only one thickness of metal, and cone-shaped to give them sufficient strength and stiffness as shown by the first of the two figures on this page.

The old method of packing large pistons is shown in the following

figure. The bottom side of the piston was formed with a flange, and the upper side with a recess to receive the "*junk ring.*" Between this flange and junk ring, J R, a packing or expansion ring, E R, of cast iron was fitted. This ring was pressed out against the sides of the cylinder by small springs, as shown in the plan. The junk ring was fixed down by pins, P, which screwed into brass



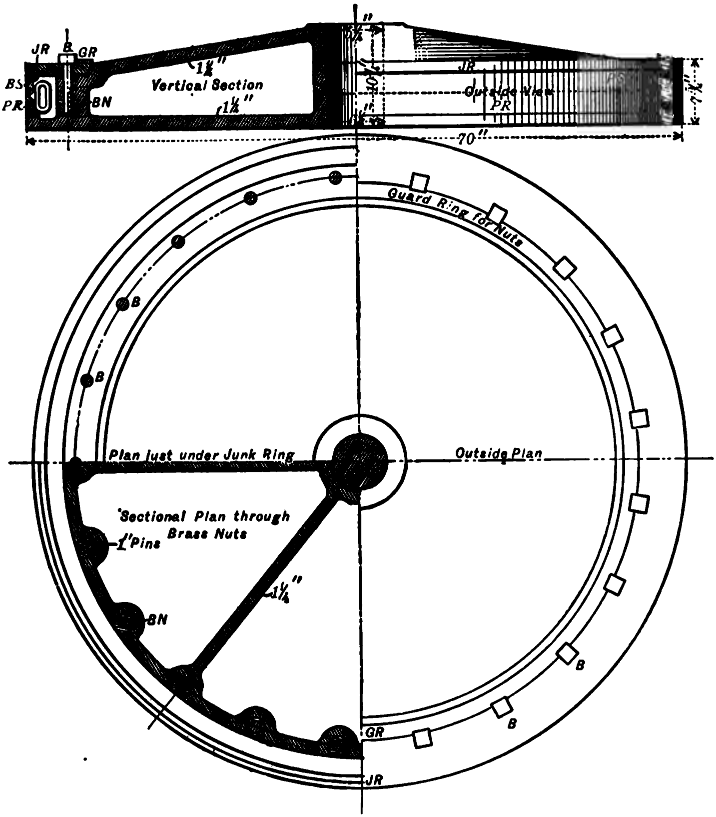
OLD FORM OF LARGE CYLINDER PISTON.

nuts, recessed into the body of the piston at suitable intervals round its circumference. The defect of this old form of piston lay in the springs, which could not be properly adjusted to give a uniform pressure on all parts of the ring. Besides which, the springs often broke, and were not free to move laterally, or to follow the bore of a cylinder when it became worn.

The St. Rognvald's Low Pressure Cylinder Piston.—It will be seen that the Buckley spring with which this piston is fitted consists of a straight spiral spring, bent into a circle just like that of the spiral spring in the Lancaster piston. It forces the two piston rings out against the walls of the cylinder, and at the same time presses them firmly between the junk ring and the under side of the piston. The pressure between the piston rings and the cylinder, results from the natural elasticity of the spiral spring trying to regain its natural shape. There is, therefore, not much danger of excessive friction being set up between the rings and the sides of the cylinder, if the whole has been properly proportioned for and fitted into the cylinder.

The packing rings in most pistons are made of hard springy cast-iron, turned to a slightly larger diameter than the bore of the cylinder, and afterwards cut across to permit of compressing and of inserting them into the cylinder along with the piston.

Specification for the s.s. "St. Rognvald's" Pistons.—To be of cast iron, 1½ inch thick, turned to size of cylinders, and made hollow with strong feathers uniting top and bottom metal, fitted with Buckley's patent packing rings, and springs. The pistons to be turned tapered for inner edge of junk ring so that it can be easily removed. The junk ring to be secured with square-headed screw pins, screwed into brass nuts recessed into the body of the piston; the heads of the screw pins to be secured with solid guard rings. No core holes to be made in top or bottom metal of pistons.



S.S. "ST. ROGNVALD'S" LOW-PRESSURE CYLINDER PISTON.

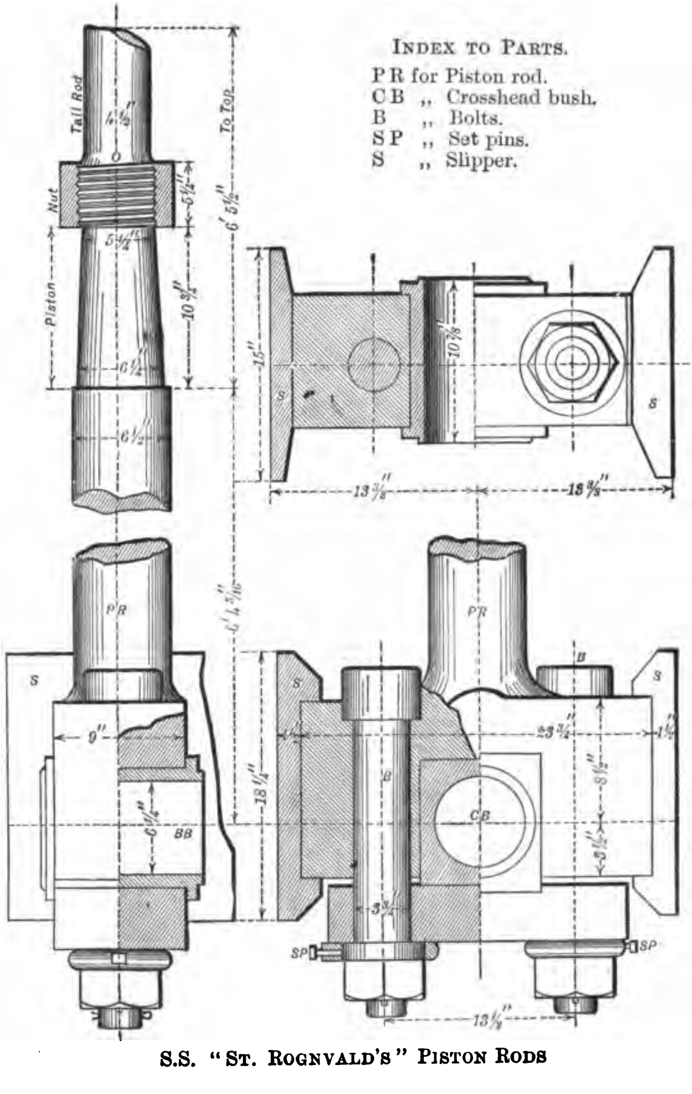
INDEX TO PARTS.

J R for Junk ring.	G R for Guard ring for bolt heads.
B ,, Junk-ring bolts.	B S ,, Buckley's spring.
B N ,, Brass nuts.	P R ,, Packing rings.

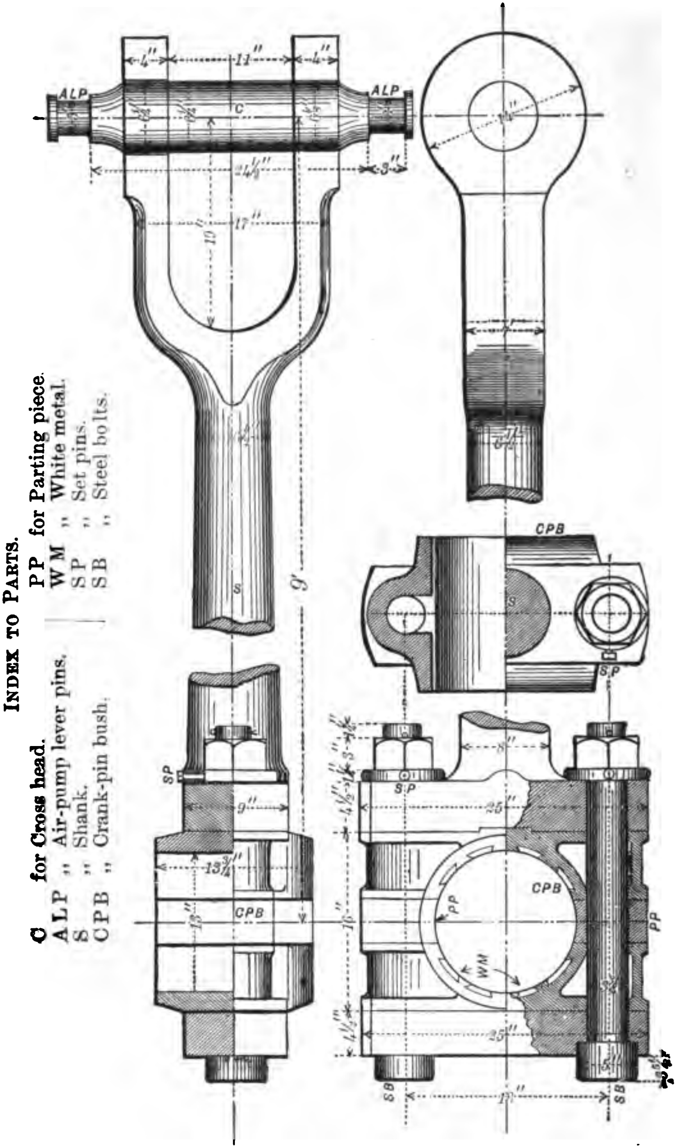
Piston Rods and Crossheads.—Piston rods are for the purpose of joining the piston to the connecting rod or direct to the crank shaft in the case of oscillating engines. They are usually made of forged mild steel, turned round, and parallel with tapered or conical ends, the one end being carefully fitted and bolted to the piston, as in the following illustration, and the other keyed to the crosshead.

In the following figure the part which connects the end of the piston rod to the connecting rod is termed the *crosshead*. In direct-acting engines, the crosshead requires to be supported by guides, in order to bear the side pressure thrown on it by the oblique action of the connecting rod. If the crosshead were not supported, and the piston rod not guided in any manner, then this side pressure (or pressure at right angles to the direction of motion of the piston) would cause injurious bending of the piston rod, and very excessive wear of the glands and packing in the stuffing boxes. In the case of a beam engine, the intervention of the parallel motion obviates the necessity for guides, since the piston-rod end moves in a straight line, and the side pressure is supported by the parallel motion bars. If the wear at the joint of the cross-head and connecting rod is intended to take place in the connecting rod, the pin which passes through both is *fixed* in the crosshead or forms part of it; and the connecting rod rotates through a certain angle about the pin, and is fitted with bushes in order to provide for the wear. If, however, as is more generally the case, the wear is imposed upon the crosshead, the pin is then fixed in the connecting-rod end, and the crosshead is provided with a bush where the pin passes through it. The pin therefore oscillates with the connecting rod, as shown in our figure. A square hole is cut out of the solid steel to receive the bush, which is formed in halves. The connecting-rod end is forked, and passes over the ends of the bush. The pin is prevented from turning in the connecting rod, and all the wear takes place in the crosshead bush. The halves of this bush are held together by a wrought-iron cover with bolts passing through it. These bolts must be of sufficient section at the bottom of the thread to withstand a tension equal to the initial effective pressure of the steam multiplied by the area of the cylinder. The crosshead is carried out at the sides to receive two flat cast-iron slide plates or slippers, which bear against the planed columns, and resist the side pressure of the connecting rod. These plates fit round the crosshead with three flanges only, so that they may be pushed into position, or taken out without disconnecting any of the larger parts; and they are prevented from slipping out at the one side by small screwed pins which are fitted in all round.

S.S. "St. Rognvald's" Piston Rods.—To be forged of mild steel, well fitted to the pistons, and secured to same by a nut (not recessed into piston). Rods to be 6½ inches diameter below pistons, and 4½ inches diameter above pistons. The lower ends (or crossheads) to be forged solid, slotted, and fitted with strong hard brasses (flat top and bottom) secured with malleable-iron covers and two steel bolts, 3¾ inches diameter, with guard rings on the nuts. Steel pinching pins, also split pins, to be put through the points of these bolts.



S.S. "St. Rognvald's" Piston Rods



S.S. "ST. ROGNVALD'S" CONNECTING RODS.

For engines which require to rotate in one direction only, a slide block on one side of the piston rod (that side against which the connecting rod thrusts) is all that is necessary, and frequently marine engines, which are but seldom required to be driven backwards, are thus fitted.

Connecting Rods.—If an engine connecting rod were of infinite length (*i.e.*, so long as to remain always parallel to the piston-rod), there would be no side pressure on the guides of the engine, and the motion of the piston and crank would be a simple harmonic motion. But in practice, a certain definite length must be assigned to the connecting rod, therefore a certain amount of pressure is always thrown on the engine slides, and a certain amount of irregularity must take place in the motion. The shorter the connecting rod, the greater is the pressure on the guides, and the greater the irregularity in the motion. In practice, the length of the connecting rod, varies from two to three times the length of the stroke of the engine. Connecting rods as short as the former proportion are found in marine practice, whilst those of the latter length are common in land engines. In some inverted-cylinder marine engines, especially those of the Royal Navy, which must be kept low down in the vessel, there is not sufficient head room for connecting rods equal to two strokes in length, and, as a matter of necessity, shorter rods require to be put in; but they do not work satisfactorily, and create excessive pressure between the slides and blocks.

Connecting rods require to stand alternately a tensile and a compressive stress, and to resist the latter without bending. They are usually made larger in diameter at the middle than at the ends, or gradually tapered from crosshead to the crank-shaft end. The ends of connecting rods are formed in a variety of ways, but, as a rule, the crosshead end is forked, and has simply two solid eyes, as shown by the illustration.

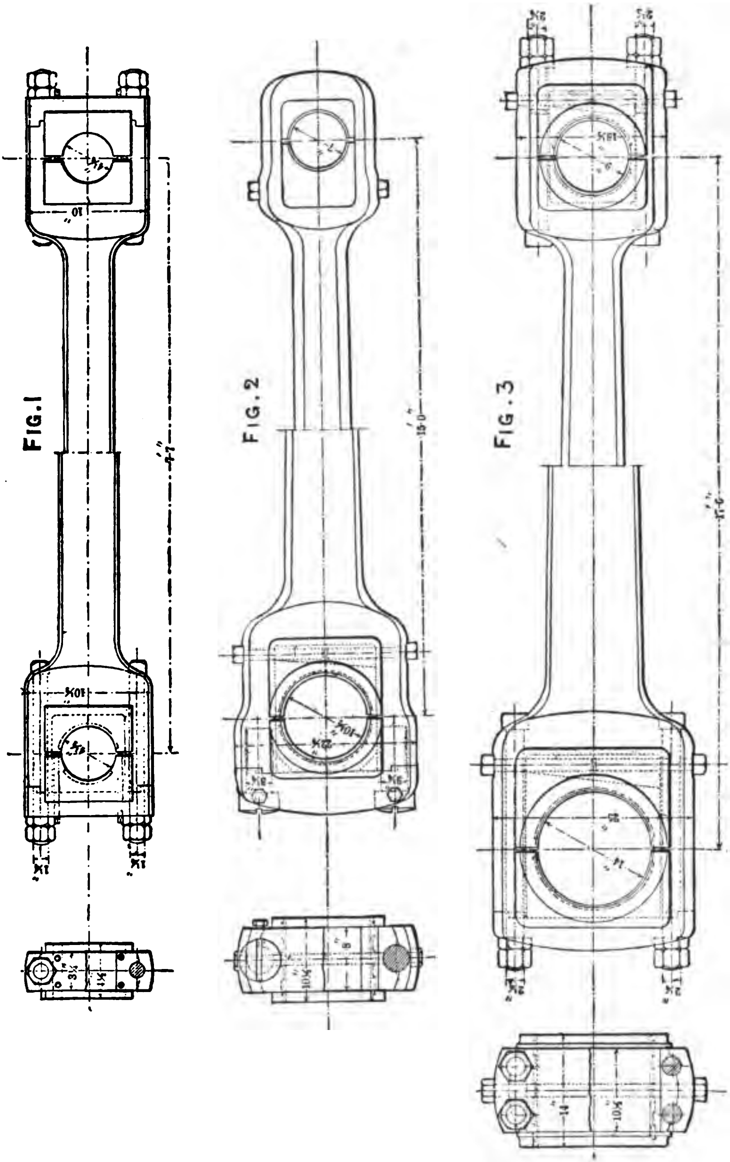
S.S. "St. Rognvald's" Connecting Rods.—To be forged of best selected scrap iron with solid double jaw at upper end. Smallest diameter of rods to be 6½ inches, tapering to 8 inches at lower end, length between centres 9 feet. Hard brasses to be secured to lower ends, with two well-fitted steel bolts, S B, 3¾ inches diameter, having guard rings with steel pinching pins, S P, and split pins through points of bolts. The lower end brasses to have four strips, ½ inch thick, of approved white metal, W M, each 2 inches broad, fitted in each half of brass with ½ inch of brass between them, and finished $\frac{1}{16}$ inch above surface of brasses. Parting pieces, P P, of cast iron, 3 inches thick, to be fitted between brasses, so that they can be removed without taking out the bolts for the purpose of stripping and taking up the wear.

In *The Practical Engineer* * attention was lately drawn to a

* Extract from paper read before the American Society of Mechanical Engineers, by Mr. W. F. Mattes. See *The Practical Engineer*, August 10, 1888.

form of connecting rod which had been adopted in America with very good results. (See following figures.)

It differs from the ordinary "marine" rod, first, in having jaws of sufficient length to hold both boxes; and, second, in having a cap which hooks over projections on the jaws. These projections are turned concentrically with the rod, and the cap hooks are counter-bored to match. The cap is thus held in position by the combination of hooks, box flanges, and bolts; but the long jaws and the counter-bore of the cap relieve the bolts of any other duty than merely clamping the parts together; and no particular accuracy need be observed, either in turning the bolts or in drilling the holes for them. As compared with rods having the outer box secured by a transverse bolt, passing through eyes in the jaws, several advantages are claimed. The flat parallel sides of the head facilitate the operations of forging and finishing; the tensile stresses are taken by bolts, in which the required strength can be easily and certainly secured, instead of by eyes, of uncertain condition, cut out of the large forging; an unsightly swelling at the end of the rod is avoided and the weight sensibly reduced. As compared with the old strap rod, the new form is cheaper and better. As compared with the solid-head rod, the open end is a great convenience, except on crosshead ends, where the pins are removable. The jaws hold the boxes with equal rigidity, permit the use of full flanges on both boxes, and do away with loose collars on the crank pins. Fig. 1 shows a plain form of the new rod. This was designed for use in pairs, connecting the ends of a crosshead with a pair of fly-wheels. In such a case it is usually safer to take up the wear by liners, rather than by wedges or cotters. The opposing screws pass loosely through the caps, and are threaded into the boxes. The bolts have round heads slightly countersunk, and are kept from turning by a spline. Fig. 2 is the rod used in a pair of horizontal, coupled, blowing engines, with 52 inches by 60 inches steam cylinders. Here wedges are used for tightening up the brasses, and, to clear the adjusting screws, tap bolts, instead of through bolts, are adopted to secure the caps. As before, the holes are loosely drilled through the caps, the holes in the rod being threaded by special taps. The bolts are steel, $3\frac{1}{2}$ inches in diameter, and are chased five threads to the inch. All parts, excepting the boxes, are hammered steel. The wedges are full width, and threaded for the adjusting bolts, which are in tension. The boxes are of "Eureka" cast steel, and fully faced with babbitt. Fig. 3 is a rod designed for a double crank, where a longer journal, and consequent wider head, admit four through bolts, spaced to clear the wedge-adjusting screws. The crosshead end has the wedge under the cap, an arrangement that tends



to preserve the correct length between centres of journals. Practically the same end may be secured in a rod like Fig. 2, by the occasional introduction of a liner between the cap and the box. In the construction of these rods, the head is first forged solid. Holes are then drilled for the interior angles, and a block slotted out, forming the jaws. As this operation, particularly in large sizes, is likely to cause a slight springing, it should be completed before the projections on the jaws are turned to a finish. The boxes may then be fitted, and the outer ones utilized as a centre for finishing the projections.

LECTURE XXI.—QUESTIONS (*continued*). *

17. How is the piston rod of a steam engine made to work steamtight through the cylinder cover? Sketch the arrangement in plan and sectional elevation, and state the material employed for each part of the combination. How is the piston made steamtight? (S. and A. Exam., 1894.)

18. What is the object of a cylinder escape valve, and where is it placed? Sketch a sectional elevation of such a valve. To what extent is it usually loaded? (S and A. Exam., 1893.)

* See Appendix for more recent S. & A. Questions.

LECTURE XXI.—QUESTIONS.

1. Sketch sectional front elevation only, and describe by an index of parts the cylinders, cylinder covers, valve ports, pistons, and piston rods, with glands complete, of a modern compound inverted-cylinder marine engine. Write out in your own words a specification for the various parts shown in your sketches, referring to each part by the letters in your index.

2. In a compound cylinder engine, sketch a sectional side elevation only, through half of each of the cylinders.

3. Sketch, and describe by an index of parts, a front and a side elevation of the piston, piston rod, crosshead, and connecting rod of the low-pressure cylinder of a compound inverted-cylinder marine engine. Write out a specification in your own words for these various parts, referring to each part in your sketch by the index letters.

4. Sketch and describe an ordinary form of piston for a stationary engine. Show the packing rings and the attachment of the piston rod. Name the materials employed in the construction of the several parts, and give reasons for employing the different materials. (S. and A. Exam., 1887.)

5. Sketch and describe the method of keeping the piston rod steam-tight in the cylinder cover. (S. and A. Exam., 1888.)

6. Draw in section the cylinder of any steam engine, showing the piston rod and mode of securing it to the piston. Show also the slide valve just on the point of cutting off steam, and place the piston in the proper position, marking the directions in which the piston and slide valve will be respectively moving. (S. and A. Exams. 1892.)

7. Sketch the piston for a large low-pressure cylinder marine engine, showing the metallic packing ring, and the manner in which the joint in this ring is made, as well as the contrivance for holding the same in its place. How was a piston formerly packed with hemp? What is the junk ring?

8. Sketch the most common and serviceable form of crosshead and guide for a vertical marine engine. How are the rubbing surfaces kept oiled?

9. Give complete free-hand sketches (side view and plan) of a marine-engine connecting rod, and explain how the various parts are machined and fitted together, as well as how the bearings are kept lubricated when the engine is working.

10. Describe, with sketch, some mode of constructing the end of a marine engine connecting rod, pointing out the provisions made to allow for wear and to reduce friction.

11. Sketch the crank-shaft end of the connecting rod of a marine engine, and describe the means employed for lubricating the rubbing surfaces.

12. Sketch a relief or escape valve for a cylinder, and explain its use and action.

13. Given length of stroke 42", thickness of piston 9", and clearance at each end $\frac{3}{4}$". What must be the length of the cylinder inside? *Ans.* 52$\frac{1}{2}$ inches.

14. If a cylinder is 33$\frac{5}{8}$" long inside, and the piston 5$\frac{1}{4}$" thick, while the stroke is 27", what is the clearance at each end? *Ans.* $\frac{5}{8}$, $\frac{1}{16}$ inch.

15. Sketch the end of the connecting rod of a locomotive engine which embraces the crank pin. Show clearly the method of tightening the brasses on the crank pin by a gib and cotter. (S. and A. Exam., 1889.)

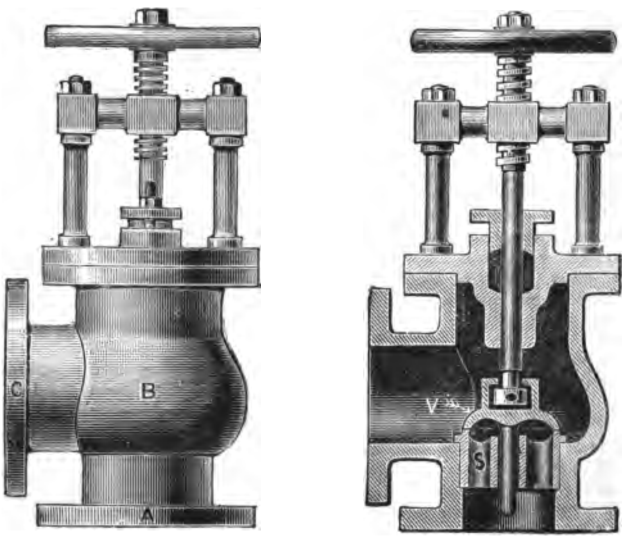
16. Show by a sketch, the manner in which the crosshead in a direct acting horizontal engine is kept in its true path by guide bars. Why are rectangular notches usually cut across the ends of the sliding surfaces of guide-bars? (S. and A. Exams. 1892.)

LECTURE XXII.

CONTENTS.—Stop Valves—Double-beat or Equilibrium Valves—Cornish Double-beat or Crown Valve—Throttle Valve—Slide Valves—Murdoch's Long D Slide Valve—Locomotive or Common Short D Slide Valve.

Stop Valves.—These valves are used for the purpose of stopping and regulating the passage of steam from the boilers to the engines. One of these valves is fitted to each boiler, and to the main steam pipe close to the engines, so that any, or all, of the boilers may be placed in communication with the main steam pipe, and the latter with the valve casing of the engine.

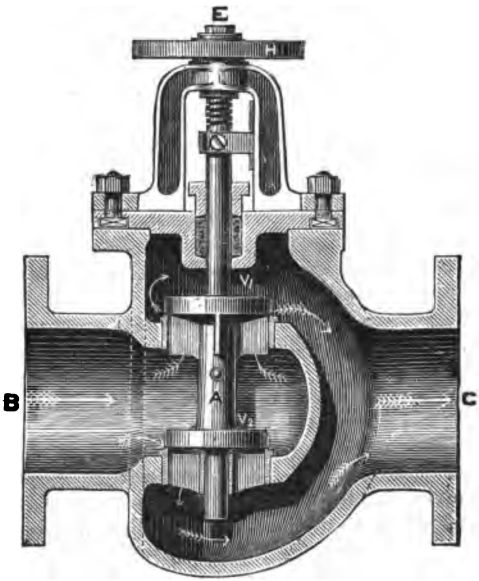
The form and construction of the stop valve, which is generally placed between the boiler and the steam pipe, are shown by the following outside view and section.



TURNBULL'S STOP VALVE.

The apparatus consists of a simple chest of cast iron, with a flange, A, which is bolted to the boiler, and another flange, C, bolted to the steam pipe. The valve is opened or shut by means of a wheel, to the centre of which, and also to the valve, is fitted a spindle with a square-cut screw thread near the handle or wheel. This screw works in a nut formed in the cross arm between the two wrought-iron pillars, screwed into the cover of the stop valve chest. The lower part of the spindle is turned truly round and parallel, and moves in an ordinary steam-tight stuffing box and gland. The area of the valve should be such as not to throttle or wire-draw the steam when the valve is full open, and there should also be plenty of space round the top of the valve to permit the steam to flow freely into the steam pipe or to the valve casing. If too small a valve, or if too contracted a passage, be used, then a fall of pressure between the boiler and the engine is sure to take place.

Double-beat or Equilibrium Valve.—The form of valve just described is often used in the case of small powers, to admit and cut off steam between the steam pipe and the engine; but where the steam pipe is large and the pressure great, a "balanced" or "equilibrium" or "double-beat" stop valve (as shown in the



ALLEY & MACLELLAN'S DOUBLE-BEAT STEAM STOP VALVE.

following figure) is used. It consists of two conical valves on the same spindle. The advantages obtained by using this form of valve are twofold. In the first place, if the valves are properly proportioned, the pressure of the steam acting on the upper side of the one and on the under side of the other valve very nearly balances, so that a much less effort will open or close the valve than in the case of the former kind, where the full pressure acts on the full area of the valve. In the second place, this double-beat valve only requires *half* the lift for the same area of pipe in order to let "full bore" of steam through. This may be easily proved, thus:—

Let r = internal radius of valve seat,
h = height to which valve must be lifted to pass full bore of steam,
πr^2 = cross area of valve seat,
$2\pi r$ = circumference of valve seat,

$$\therefore 2\pi r \times h = \pi r^2$$

$$h = \frac{\pi r^2}{2\pi r} = \frac{r}{2}.$$

Consequently, if there be but one valve, it must be lifted to a height equal to $\frac{1}{2}$ the radius, or $\frac{1}{4}$ of the diameter, in order that the area of the parallelogram strip represented by the lift shall be equal to the cross area of the pipe; but if there be two valves connected together, as shown by the following figures, then it need only be lifted half the above distance, or $\frac{1}{8}$ of the diameter, because the steam has a free passage through both seats.

These double-beat or double-seated conical valves are frequently used instead of slide valves, more especially in slow-working engines, such as those employed for pumping water, and in the American beam engines for river and lake steamers. They have also quite lately been revived in the case of fast-speed engines of the Proel and the Robey automatic cut-off type, but with the addition of an air-cushioning cylinder, or "dash pot," to let them come down gently on to their seats, and thus prevent, as far as possible, wear and tear and clattering. They are also frequently used for locomotive "regulator-valves;" and, in fact, wherever the lift and the force required to open and close a valve have to be as small as possible. They have never been successfully used for safety valves, owing to the difficulty of keeping them thoroughly steam-tight under constant pressure and high temperature, since, from the form of the valves, the heat causes the spindle or shank between them to expand more than the seats and chest in which they are fixed.

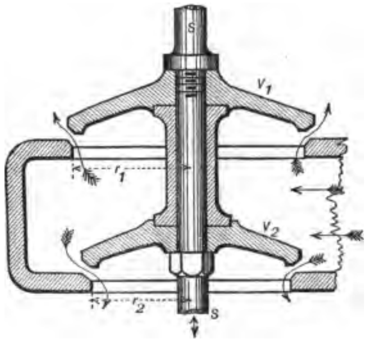
The student can easily calculate the difference in the diameters

of the two valve seats that would produce perfect equilibrium with the steam or liquid pressure used, if he is given the weight of the valve.

For, let r_1 = radius of valve V_1,
r_2 = " " V_2,
w = weight of the two valves and their spindle,
p = the pressure per square inch of the fluid.

Then, *the pressure per square inch multiplied by the difference in areas of the two valves must equal the weight of the whole valve to ensure equilibrium.*

Or, $$w = p\,(\pi r_1^2 - \pi r_2^2).$$



DOUBLE-BEAT VALVE.

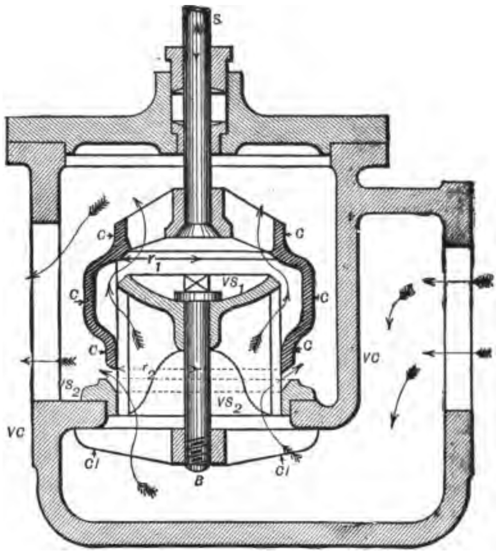
Practically, however, the largest diameter of the lower or inner valve must obviously be a little less than the smallest diameter of the upper or outer valve, in order to let the valve be put into its place.

Cornish Double-beat or Crown Valve.—Another very common form of double-beat or equilibrium valve is that known as the "Cornish crown valve," very probably owing to the chief part of the valve resembling a crown or hood, and its extensive use in connection with Cornish pumping engines, as a substitute for the slide valve, for admitting steam to enter and exhaust from the cylinders of these engines.

The next illustration is a reduced sketch from one given in Sennet's *Marine Steam Engine*, and he says that "this is probably the best form of valve for enabling a large passage to be opened and closed for the flow of steam or any fluid under high pressure."

It will be seen from the figure that the crown, C, or movable part of the apparatus, is connected to the spindle, S, by a cotter,

which thus enables it to be lifted or lowered from or on to the valve seats, V S_1 and V S_2. The upper valve seat, V S_1, is secured to the valve chest, V C, by a central bolt, B, screwed into a three-legged clamp or claw, Cl. The lower valve seat, V S_2, is simply driven hard into the lower end of the valve chest, V C. The arrows indicate the direction in which the steam or water is supposed to flow towards, through, and from the valve seats; but as far as the mere construction of the apparatus is concerned, it does not matter whether the fluid flows in the one way and out the other, or *vice versâ*, for in either case the crown or hood of the valve is in equilibrium with respect to the pressure before and after it is opened.

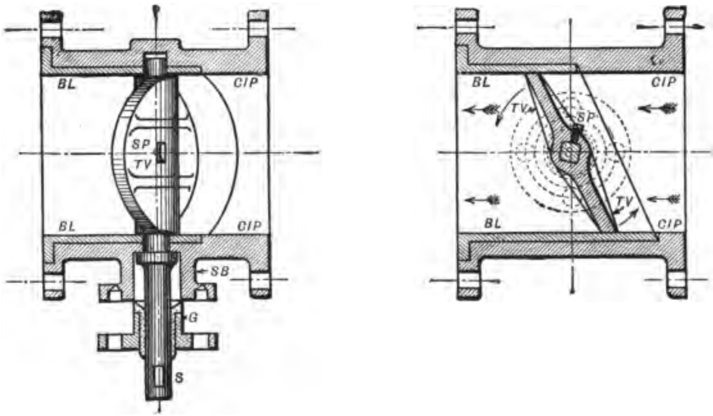


Cornish Double-beat or Crown Valve.

The lift required for a valve of this form is of course just one-half what is required for an ordinary single valve, and in this respect it is similar to the other form of equilibrium or double-seated valve already described. The same rule also applies to the finding the difference of the diameters d_1, d_2, or the excess of radius, r_1, over, r_2, which would be required for a certain weight of valve and pressure in order to ensure perfect equilibrium, if there existed no friction between the spindle, S, and the packng in its stuffing box. When used as a stop valve, it is preferable

to work the spindle by a wheel-handle and a screw, as in the first two cases illustrated in this Lecture, because the back lash is less, and the certainty by which it can be moved is greater.

Throttle Valve.—This was the original form of regulator-valve introduced by Watt (see fig., p. 171). In marine engines there are generally two of these valves placed between the engine stop valve and the slide-valve casing. The one is connected to a lever on the starting platform, whereby the engineer may suddenly cut off the steam from the engines in case of an accident, or throttle or wire-draw the steam by partially closing it when going slowly for a short time; the other one is connected to the governor. In stationary land engines of the ordinary type the former of these throttle valves is dispensed with, and in locomotives neither of them is employed. The construction and action of this valve will be readily understood from the following sectional figures.



THROTTLE VALVE.

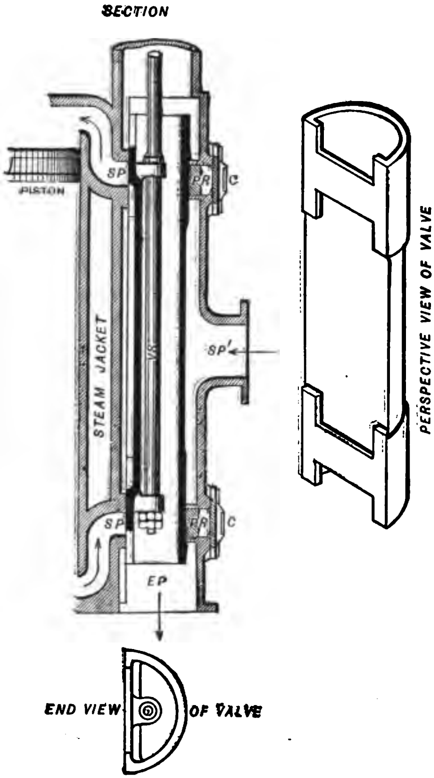
The throttle valve, T V, is simply an elliptical plate or door, fixed upon a central spindle, S, by a key or a taper pin, or, as shown in the above figure, by a set pin, S P. The inner end of this spindle is supported by a round hole in the pipe, whilst the outer end projects through a steam-tight stuffing box, S B, and gland, G. When closed, the throttle valve bears all round on the inside of a brass liner, B L, let into a cast-iron pipe, C I P. This short piece of pipe is bolted between the engine stop valve and the valve casing, and when there are two throttle valves (as already mentioned in the case of a marine engine) both are contained in the one piece of pipe. The governor throttle valve is, however, seldom made elliptical, but generally circular, as it is only used for check-

ing the flow of steam and not for cutting it off entirely, as in the case of the hand-moved one. Neither form can, however, be relied upon as thoroughly steam-tight, owing to the difficulty of fitting them exactly, and the difference of expansion between the valve and the pipe containing them. The direction in which the throttle turns and the direction in which the steam flows through the pipe are indicated by arrows. The throttle valve is a truly balanced valve, since the steam acts on equal areas on each side of the spindle.

S.S. "St. Rognvald's" Stop Valve and Throttle Valves.—A stop valve to be fitted to the main steam pipe, and to the high-pressure cylinder valve casing. This stop valve to contain separate hand and governor throttle valves. The stop valve and the ordinary throttle valve to be worked from the starting platform.

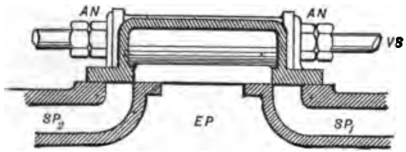
Slide Valves.—The double-beat form of valve is an excellent piece of mechanism for admitting steam to enter and exhaust from the cylinders of certain classes of land engines; but the necessary gear required to work it quietly and successfully is too complicated, cumbersome, and expensive for locomotives, ordinary marine engines, and the commoner and smaller classes of fast-speed land engines. This was recognized very early in the progress of the steam engine, for we find that in 1799 Murdoch, who was associated with Watt in the improvement of his double-acting engines, patented an entirely different form of valve for this purpose, which depended upon a to-and-fro sliding motion for its action. This was, no doubt, the origin of all the numerous forms of slide valves which have been introduced since that time. We have already discussed in an elementary manner the action of the ordinary or locomotive short D slide valve, and its peculiarities of lap, lead, and travel. We now propose to illustrate and describe a few of its forms which have been or are in common use.

Murdoch's Long D Slide Valve.—This, the first kind of slide valve, received its name from the resemblance of its cross section to the letter D, as may be seen from the following figure. It consists of a long semicircular pipe, the flat side of which slides to and fro against the face of the steam ports leading to and from the cylinder, whilst the semicircular back moves against a metallic packing fixed near each end of the valve. Steam enters the valve casing by the back steam pipe, S P′, and passes round the space on the outside central part of the slide valve to the steam ports, S P, in the direction indicated by the arrows, being prevented from reaching the ends of the valve casing by the steam-tight packing ring, P R. Each end of the valve casing is in direct communication with the condenser (the upper end through the central opening or pipe

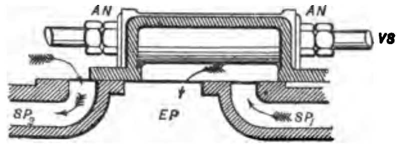


MURDOCH'S LONG D SLIDE VALVE.

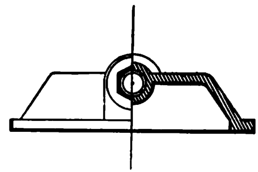
formed by the D of the valve); so that when the valve moves up sufficiently far, the inner end of the upper steam port, S P, is placed in direct communication with the boiler, while the outer end of the lower steam port, S P, is opened to exhaust, and *vice versâ*, when the valve moves down. If the metallic packing were made and kept thoroughly steam-tight, this kind of valve would be free from the objection arising from great pressure between its face and the face of the steam ports, and therefore it would offer little resistance to being moved up and down; but in practice it has been found very difficult to make and keep these packings steam tight, and consequently it has, after many lengthened trials, been laid aside for improved forms of the locomotive or short D slide valve.



Valve at its Mid-stroke.



Valve Full Open to Steam and Exhaust.



End View—Cross Section.

LOCOMOTIVE OR SHORT D SLIDE VALVE.*

Locomotive or Common Short D Slide Valve.—This form of valve is by far the most common in small land and marine engines, and is almost universally adopted for locomotives. When, however, we come to large engines using high-pressure steam, the friction to be overcome in driving this unbalanced or unrelieved form of valve is so great, that resort is had to modifications, termed the "double-ported," "treble-ported," or "quadruple-ported" slide valve; and when an earlier cut off is desired than before half stroke, sufficient opening to steam can only be obtained from it by excessive travel, large leads, or very broad steam ports. Long travel means loss of power in driving the valve; broad ports, loss of power due to overcoming the friction consequent on the greater pressure between the larger area of valve and valve face; while too large leads produce shocks to the connecting rod, &c. &c., just as much as too small leads would do. Under these circumstances, expansion valves are fitted to the back of a modified form of short D slide valve.

The above figures represent the short D slide valve—(1) in the middle of its stroke, with both steam ports, SP_1, SP_2, covered; (2) when it has opened the steam port, SP_2, by the full amount, and exhaust is freely taking place from the other side of piston through SP_1 to the exhaust port EP, as shown by the arrows; (3) a half outside and half sectional end view.

* This valve is sometimes inaccurately termed a "three-ported valve," the expression meaning a valve working on a valve face with two steam and one exhaust ports.

LECTURE XXII.—QUESTIONS.*

1. Sketch and describe an ordinary single conical stop valve. Mention the positions where such a valve is placed, and for what purposes.

2. Sketch in section a steam stop valve for allowing steam to pass from a marine boiler to the engine, and mention some details of construction whereby the due action of the valve is ensured.

3. Point out some method of rendering a steam valve "balanced." Sketch a balanced as well as an unbalanced valve.

4. Describe a double-beat or equilibrium steam stop valve. The upper side of the valve is 11 inches in diameter and the lower side 10½ inches. What force will be required to open it when the steam has a pressure of 100 lbs. above the atmosphere? *Ans.* 971·2.

5. Supposing that drop valves are substituted for the slide valve in the double-acting engine, how many would be required? Make a sketch, showing their position, together with the steam and exhaust passages. How are drop valves worked? Sketch the contrivance.

6. Describe an ordinary double-beat valve, making such sketches as may be necessary for showing the construction of the valve and the principle on which it acts. (S. and A. Exam. 1888.)

7. Prove that the lift required by a single valve is just one-fourth the diameter in order to let the full quantity of fluid pass that can get through the seat of the valve. Also show that a double-beat valve requires only half the lift of a single valve of the same mean diameter in order to pass the same quantity of fluid in the same time.

8. Show that by a double valve a steam passage may be opened by a small force. Sketch the contrivance, showing how the steam passes. Make a sectional sketch of a Cornish crown valve, and explain the principle of its construction for the above purpose. (S. & A. Exam. 1894.)

9. The diameter of a steam pipe is 12½ inches, and the upper and lower discs of an equilibrium valve which closes it are 12 and 10½ inches respectively. Sketch the arrangement, and find the lift of the valve when the opening of the valve is equal to the area of the steam pipe. (S. and A. Exam. 1890.) *Ans.* 1·73 inches.

10. Sketch an equilibrium or double-beat valve. Where is such a valve introduced? If the upper and lower discs of a double-beat valve are 12 and 11 inches in diameter respectively, and the pressure of the steam is 50 lbs. per square inch, while there is a pressure of 3 lbs. per square inch in the space between the upper and lower valves, what pressure would be necessary to open the valve ($\pi = 3\frac{1}{7}$)? (S. & A. Exam. 1891.) *Ans.* 849·4 lbs. nearly.

11. Sketch and describe the action of an ordinary "throttle valve," and mention for what purposes it is used. How does it act as a reducing or wire-drawing valve?

12. Sketch in section a long D slide valve having lap on the steam side, together with the steam ports and passages. Explain the action of the valve, and show the manner in which the exhaust steam is passed to the condenser.

13. Sketch in section and end view, with steam ports, an ordinary locomotive cylinder with a D slide valve. Put the valve in its middle position, and also when it has opened one steam port by the amount required for lead. Show the direction of the flow of the steam. Why is this valve not suited for an early cut-off and for large engines with high-pressure steam?

* See Appendix for the most recent S. and A. Exam. Questions.

LECTURE XXIII.

CONTENTS.—Double-ported Slide Valve—Piston Valve—Expansion Valves—Gridiron Expansion Slide Valve—Expansion Valve on Back of Slide Valve—Starting and Reversing Gears—Single Loose Eccentric Gear—Stephenson's Link Motion—Link Motion of the s.s. *St. Rognvald*, and Specification for Valves and Link Motion.

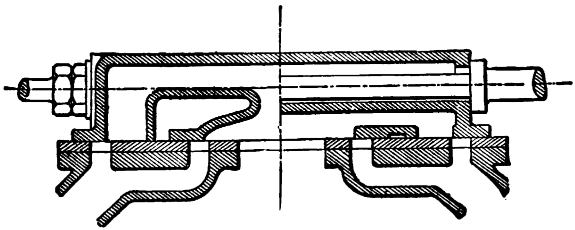
IN the last Lecture we drew attention to the great power absorbed in simply driving the ordinary D slide valve. To impress this fact upon the student, suppose the case of a locomotive D slide valve, 16″ broad by 10″ long, with a travel of 6″, working under a steam pressure of 160 lbs. per square inch. What power will be absorbed in driving each of the locomotive slide valves, when the crank shaft is making 200 revolutions per minute, and assuming the co-efficient of friction between the face of the valve and steam-port bars to be 0·1?

Area of slide valve	=	16″ × 10″ = 160 sq. ins.
Total pressure on valve	=	160 sq. ins. × 160 lbs. = 25,600 lbs. (over 10 tons).
Force required to move valve	=	25,600 lbs. × ·1 (co-eff.) = 2560 lbs.
Work expended in moving valve each revolution of crank The travel of valve being 6″ or ·5′, it moves 1′ during each revolution of crank	=	Force × distance moved = 2560 lbs. × ·5′ × 2 = 2560 ft.-lbs.
Work expended each minute	=	2560 ft.-lbs. × 200 = 512,000 ft.-lbs.
Power absorbed in working one slide valve	=	$\frac{512,000}{33,000}$ = 15·5 horse-power.

This calculation neglects the power absorbed in moving the mere dead weight of the valve, as well as that due to the friction of the valve spindle in its stuffing box and guides, since these quantities may be supposed to be constant for any kind of valve used—so far as our purpose is concerned—which is simply to impress upon the student that a very large proportion of the power developed by an engine is absorbed in merely working one of its most essential parts, viz., the slide valve. This fact has led engineers to devise many forms of slide valves, with the object of overcoming this great waste of power. One of these devices is known as the "Double-ported Valve,"

Double-ported Slide Valve.—This form of slide valve aims at lessening the power required to drive the valve by reducing the travel.

This is effected by having two steam openings to each steam port of the cylinder, instead of only one, as in the case of the common D slide valve. The outer opening admits steam direct from the valve casing, and exhausts through the outermost opening in the valve by a passage formed round the back of it into the exhaust port, while the inner opening to the steam-port gets steam from the valve casing through a transverse opening in the valve, and exhausts directly into the exhaust port. A valve of this kind may, therefore, afford the same opening to the steam as an ordinary locomotive slide valve with half the travel, and, consequently, with half the expenditure of power to drive it, as far as regards

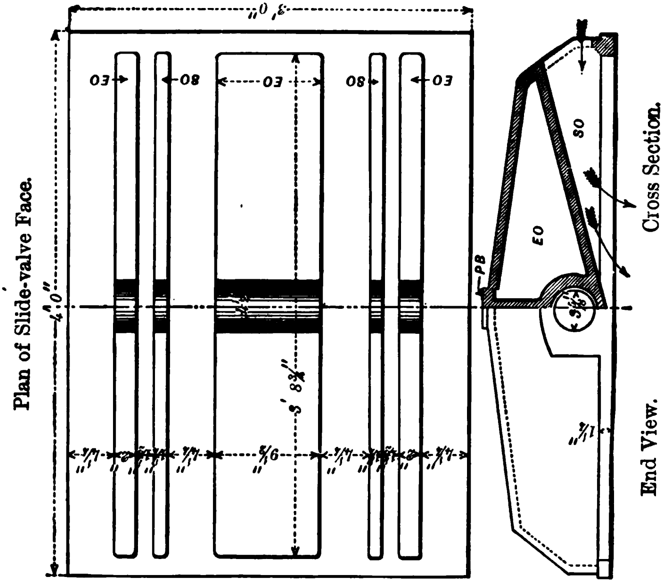


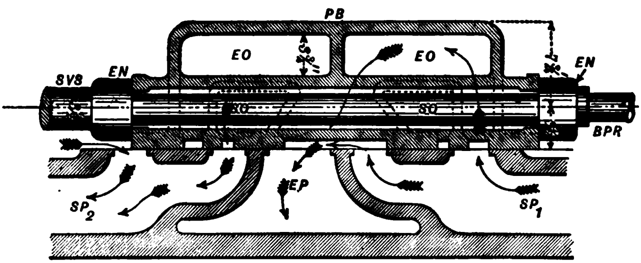
COMMON DOUBLE-PORTED VALVE AT ITS MID-STROKE.

the effect of the direct pressure to steam on the back of it, but this is sometimes still further reduced by causing the back of the valve to bear evenly upon a steam-tight opening or pressure relieving frame, in direct communication with the condenser. In very large marine engines, treble-ported and even quadruple-ported slide valves have been resorted to with the same object, viz., a reduction in the power required to drive them, by lessening the travel. Neither of these plans is thoroughly satisfactory, for they only partially diminish the power required to drive the valve.

The above illustration shows a longitudinal section, with the valve at its mid-stroke, whilst that on the next page shows the valve when opening the steam port by the full amount, as well as a plan of the face of the valve and an end view (half outside view, half section).

Specification for the s.s. "St. Rognvald's" Slide Valves.—To be placed on the forward side of their respective cylinders. The low-pressure cylinder valve to be double ported, the high-pressure cylinder valve to be single ported, and both to be made of hard close-grained cast iron. These valves to be carefully fitted to valve face by scraping, and rendered perfectly steam-tight,





Section through Valve and Steam Ports.

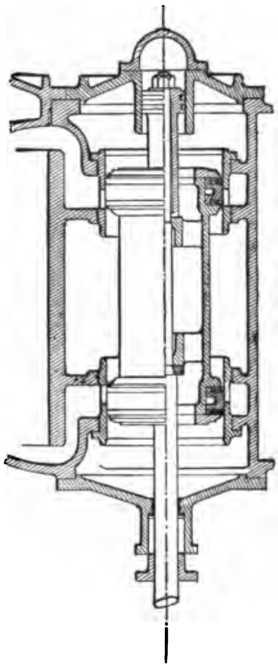
S.S. "ST. ROGNVALD'S" DOUBLE-PORTED SLIDE VALVE.

INDEX TO PARTS.

SP_1, SP_2	for Steam ports.	S V S	for Slide-valve spindle.
E P	,, Exhaust port.	E N	,, End nuts.
S O	,, Steam openings.	B P R	,, Balance-piston rod.
E O	,, Exhaust openings.	P B	,, Planed back.

➞ Direction steam takes.

Piston Valve.—As we remarked before, no thoroughly satisfactory plan has yet been devised of relieving the ordinary D slide valve from the pressure of steam upon its back surface, and, consequently, in the case of large engines, using very high-pressure steam, recourse is had to the piston valve.



THE PISTON SLIDE VALVE.

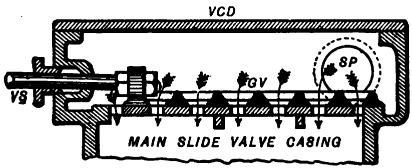
The accompanying figure of a piston valve is from Seaton's *Manual of Marine Engineering*. It will be seen from the figure that there are two steam ports and one exhaust port, as with the ordinary slide valve; but, owing to the circular construction of this valve, the steam-port area is nearly three times that of an ordinary flat valve of the same transverse dimensions (since the circumference of a circle is $\pi d = 3{\cdot}1416$ times the diameter). Further, the pressures on the sides of the valve are perfectly balanced, since they act equally all round it, and, consequently, the valve, if properly made and fitted, simply floats in a bath of steam. The valve consists of two pistons in one casting, connected together by a pipe, which is fixed to the valve spindle. There is a balance piston and cylinder, fitted immediately above them, to relieve the eccentrics from the dead weight of the valve, link motion, and eccentric rods. The piston valves are rendered steam-tight by having stiff cast-iron liners and bronze spring rings, which extend beyond the turned surface of the pistons sufficiently far to permit the steam having a free passage to the ports. These spring rings are prevented from forcing themselves into the steam ports by a series of narrow diagonal bearing bars being cast in and around the port liners, thus →**W**. These bars are truly bored out along with the liners. Steam exhausts from the cylinder round the outside of the pipe between the pistons of the valve, and enters the cylinder from each end, so that the lap of the valve is on the outside edges of the valve in the same way and to the same extent as with an ordinary slide valve. To avoid, as far as may be, the naturally large clearance

space with this form of valve, the pistons are kept as far apart as possible, so that they may be almost directly opposite to the positions where the steam enters the cylinders. All the latest engines for Transatlantic steamers, as well as many others, have been fitted with piston valves. The chief objection or disadvantage usually urged against these valves is their first cost, which naturally prevents their being commonly fitted to the low-pressure cylinder of compound, or of multiple expansion engines.

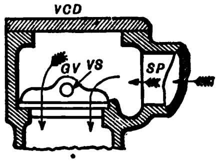
Expansion Valves.—We have already mentioned that the ordinary slide valve is not well suited for high grades of expansion, because sufficient opening to steam cannot be obtained with it for an earlier cut off than, say, half stroke, without increasing the travel and the lead, or using unduly long ports, or else subjecting the steam to considerable wire-drawing. This defect is, to a certain extent, overcome by the double-ported valve, and also by the piston valve, from the fact that they each give a larger area of opening to steam with less travel than the ordinary D slide valve.

There are, however, many special devices, called "expansion valves," which have been invented to remedy or assist the ordinary slide valve in overcoming this defect. One of the earliest arrangements was to fix a cam upon the crank shaft, with a bearing-roller on the cam, connected to an ordinary throttle valve, fixed in the steam pipe close to the valve casing. This cam was so set with respect to the ordinary eccentric working the ordinary slide valve, that it elevated the bearing roller, and consequently closed the throttle valve just before the steam had forced the piston through the desired length of stroke at which cut-off should take place. The obvious defect in this arrangement lay in the fact that the throttle valve could not be conveniently fixed sufficiently near to the slide valve, and thus the valve casing was left full of steam after the throttle valve had closed the steam pipe, which steam was not cut off by the ordinary slide valve until half stroke, or later. In order to so far remedy this defect, what are called "gridiron" expansion valves were at first fitted to seatings fixed near to the steam-pipe opening in the main valve casing, but latterly a modification of this plan has been fitted directly to the back of the main ordinary slide valve.

Gridiron Expansion Slide Valve.—The following illustration will at once convey a clear idea of the former of these plans.



Longitudinal Section.



End Section.

GRIDIRON EXPANSION SLIDE VALVE.

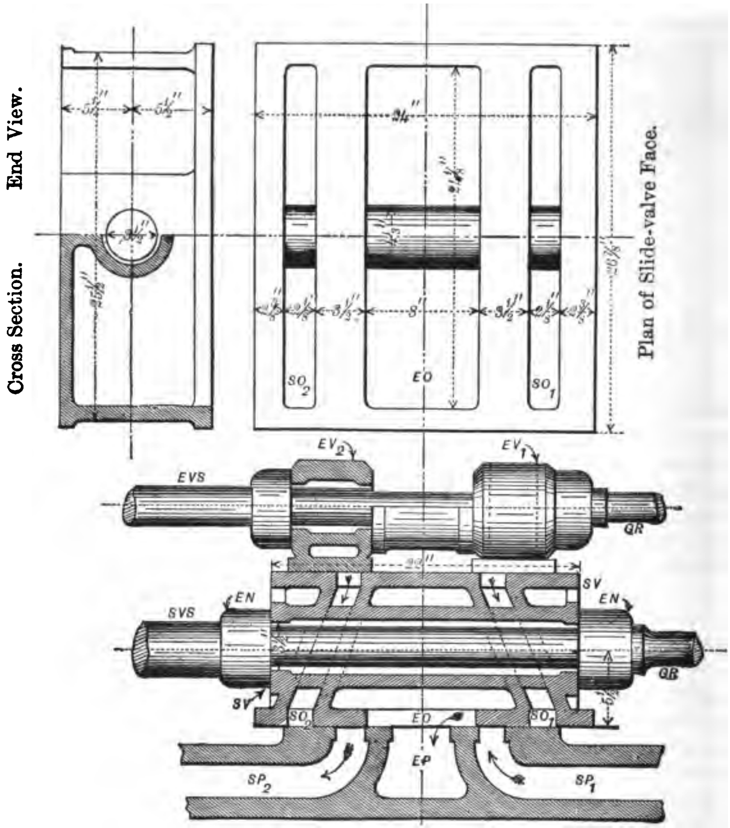
INDEX TO PARTS.

G V	for Gridiron valve.	S P	for Steam pipe.
V S	,, Valve spindle.	V C D	,, Valve-casing door.

The gridiron valve, G V (shaded by full black lines in left figure), is driven by an ordinary eccentric, keyed to the crank shaft in the same way as any ordinary slide valve. It consists of a simple flat plate, slit up into parallel strips (exactly like the opening and closing sliding part of the ventilator usually fixed immediately above the doors of railway carriages), while the flat steam-port face, upon which the valve slides, is correspondingly perforated. When the valve uncovers the openings in the port face, steam enters from the steam pipe into the main slide-valve casing, as shown by the arrows. It may be set so as to cut off at any desired part of the piston's stroke. The valve requires, from its construction, but a very small travel in order to give a large area of opening to steam; for, if 10 square inches be the opening for one slit, then 100 square inches would be the total opening, if ten such slits and valve bars were used, without any increase of travel. The same objection, however, as that stated in respect to effecting expansion by a throttle valve, fixed on the steam pipe, holds good with this gridiron valve, if it be placed simply at the mouth of the slide-valve casing; for the valve casing is then left full of steam when the gridiron valve cuts off connection with the steam pipe, and thus steam is not cut off from the cylinder until later in the piston's stroke by the main valve. In other words, the clearance space is excessive.

Expansion Valves on the Back of Slide Valves.—To avoid as far as possible this excessive clearance, gridiron expansion valves, exactly similar to that described above, are frequently worked directly upon the back of box-shaped, double-ported slide valves; but more frequently as shown in the following figure,

which represents the expansion valve and main slide valve for the high-pressure cylinder of the s.s. *St. Rognvald.*



Section through Valves and Steam Ports.

S.S. "St. Rognvald's" Expansion and Main Slide Valves for High-pressure Cylinder.

Index to Parts.

SP_1, SP_2	for Steam ports.	SV	for Slide valve.
EP	,, Exhaust port.	SVS	,, Slide-valve spindle.
SO_1, SO_2,	,, Steam openings in valve.	EV_1, EV_2	,, Expansion valves.
EO	,, Exhaust opening in valve.	EN	,, End nuts.
		GR	,, Guide rods.

It consists of a main slide valve with holes at each end, and two plates working on the back of it. These plates are kept at a fixed distance apart by collars on the spindle, and their sole action is to cut off the steam at any desired part of the piston's stroke, while the main slide valve regulates the points of admission, release, and compression. The expansion valve is worked by a separate eccentric, E V E, fixed at the forward end of the crank shaft (see front and side elevations, Lecture XX.). This eccentric is connected by its eccentric strap and rod to a straight link, actuated by a horizontal screw, and a pair of bevel pinions, so that different grades of travel, and, therefore, of expansion, may be given when required. The nearer the eccentric rod is placed in line with the expansion valve spindle, the greater the travel, and the later the cut off. Another method of effecting the same object is that known as "Meyer's Valve Gear." It is identical with the above in every respect, except that the link is dispensed with, and the upper and lower expansion plates are respectively threaded on to right- and left-handed screws cut on the expansion-valve spindle. Outside the valve casing, a wheel is fixed to the expansion-valve spindle, whereby it may be turned round, and the expansion plates moved further apart or nearer together, in order to vary the point of cut off to any desired extent.

Specification for the s.s. "St. Rognvald's" Expansion Valve.—To be fitted to the back of the high-pressure cylinder slide valve, and arranged to cut off at from 12 inches to 36 inches of the stroke of piston, and so made that the different grades of expansion can be adjusted from the starting platform while the engines are at work.

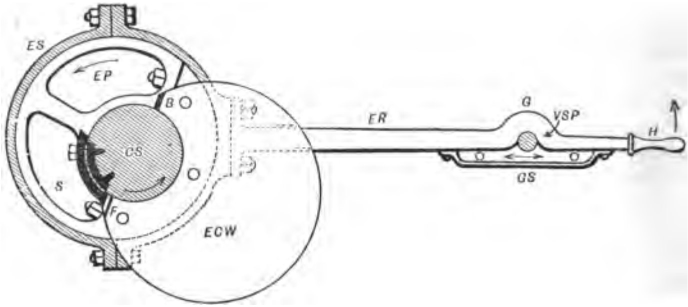
Starting and Reversing Gears.—In many land engines, such as those used in factories and for electric-light dynamos, fans, pumps, &c., there is no necessity for reversing gear; but in marine engines, locomotives, submarine cable telegraph engines, winding engines for mines, &c., reversing gear is absolutely indispensable.

Single Loose Eccentric Reversing Gear.—In slow-going paddle steamers, the reversing of the engine was formerly usually done by means of a single eccentric, fitting loosely on the crank shaft, and driven forward or backward by a projecting feather fastened to the crank shaft.

The method of starting and reversing an engine by this device is as follows:—

First.—Lift the gab, G, clear off the valve-spindle pin, V S P, by means of the handle, H.

Second.—Move the slide valve by means of a lever (not shown), so as to let steam into the steam port for moving the engine ahead or astern, as required. This causes the stop, S, which is fixed to



SINGLE LOOSE ECCENTRIC REVERSING GEAR.

INDEX TO PARTS.

E P	for Eccentric pulley.	F, B	for Forward and Back stops on E C W.
E S	,, Eccentric strap.	E R	,, Eccentric rod.
E C W	,, Eccentric counter-weight.	H	,, Eccentric-rod handle.
C S	,, Crank shaft.	G	,, Gab.
S	,, Crank-shaft stop (feather).	G S	,, Gab strap.
		V S P	,, Valve-spindle pin.

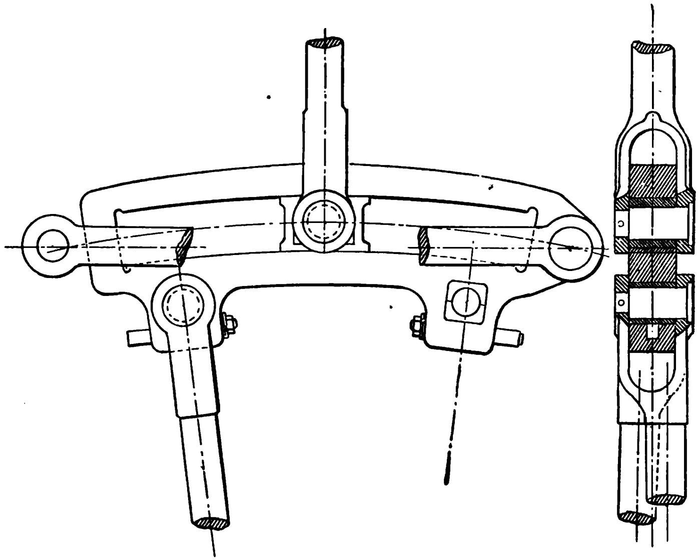
the crank shaft to come into firm contact with the forward, F, or backward, B, projection on the eccentric pulley counter-weight, E C W. This counter-weight, being bolted to the eccentric pulley, E P, in the proper position, carries it round with it either forward or backward, according to the direction in which the crank shaft forces it.

Third.—When the engine is fairly under way, drop the handle, H, when the valve-spindle pin, V S P, will fall into the gab slot, G, and the engine will go ahead or astern, as the case may be, until it is necessary to stop or reverse. The mere act of lifting the gab clear from the valve-spindle pin stops the engine, and the gab strap, G S, prevents the pin falling away too far from the eccentric rod by keeping it up to its flat under-side. It will be observed that this form of reversing gears requires some manipulative skill, as well as considerable effort to work the valve by hand. This may be easy to accomplish in the case of slow-going engines of small power, but it would be very awkward with locomotives or large high-speed compound marine engines.

Reversing Link Motion.—The reversing of an engine which has ordinary slide or piston valves is most easily effected by means of a combination of links and rods, which is known as Stephenson's "*link motion.*" In order that an engine may work in both directions, the eccentric which moves the valve must always remain at a given fixed angle in advance of the crank; and evi-

dently, with one eccentric fixed on the shaft, the position of this advance is dependent upon the direction of rotation, and is not the same when the engine rotates in either way. The arrangement by which the desired object is attained with link motion is as follows:—Two eccentrics are fitted to the crank shaft, side by side, the one being set in such a position relative to that of the crank as to control the valve's motion when the engine is going in one direction, and the other in a position to control the valve when the engine is rotating in the opposite direction. These eccentrics are connected by separate straps and eccentric rods to the ends of a link, in which a block connected to the valve rod is fixed, and which is capable of sliding from end to end. When the link is drawn to the one side, the block, being stationary, comes into line with one of the eccentric rods, and the valve is worked by the eccentric to which this rod is attached. If the link be pushed over to the other side, the other eccentric comes into play with the valve, and the engine rotates in the opposite direction. If the link be placed so that the block is at the middle of the link, then the engine stops, since the valve is thrown into its mid-position. Here the link simply oscillates about the block on the end of the valve rod as a centre, with a to-and-fro travel equal to the lap *plus* lead. The steam admitted to, say, the front end of cylinder by uncovering the steam port by the amount of the lead is cut off about $\frac{1}{4}$ stroke, and released shortly after $\frac{1}{2}$ stroke. Steam is admitted on the other side or back of piston at about $\frac{3}{4}$ stroke, and compression takes place on front side very soon after release, so that the small quantity of steam which is admitted is so hampered in its action by early release and compression and the opposing force of early admission from the other side, that, when the block is in mid-gear, the piston is brought to a halt, and the engine cannot revolve. To trace out the complete and precise action of the slide valve, and the distribution of the steam for different positions of the link, is a difficult problem, and only suited for Honours students.

The construction of these links is very varied. One form is shown in the following figure. It is a very simple form, and has been used for small engines for many years. It consists of a flat piece of iron with a circular slot in it, in which a block attached to the valve rod is fitted. This block is able to slide lengthwise along the link. The link has two snugs formed on one side for the attachment of the eccentric rods; and also a snug at one end, by which the link is hung, and may be moved back and forward so as to bring the valve rod over one eccentric rod or the other. This link gives a more irregular motion to the

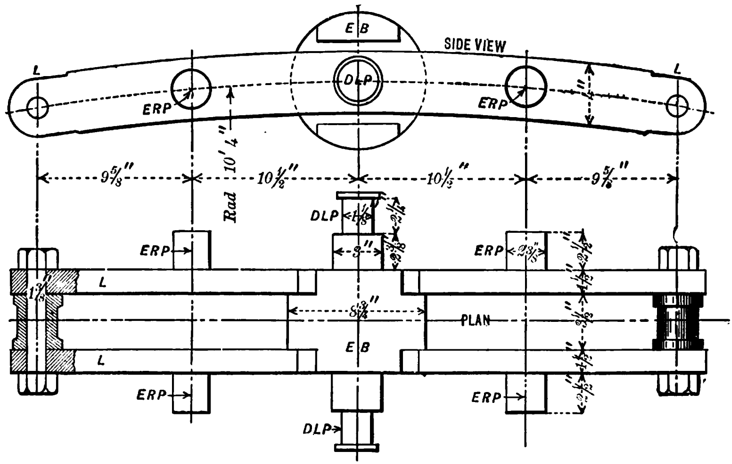


THE SLOT LINK.

valve than some of the other forms, although it works on the whole fairly well, and it is more difficult to adjust when it becomes worn.

One of the best forms of link-reversing motion (although one of the most expensive to make) is shown in the diagrams of the s.s. *St. Rognvald's* engine, and in detail on the next page. This link is formed of two bars fixed together at the ends, and with the valve block sliding between them. The eccentric rods are forked, and are attached to the links near their ends by pins, which are forged on to the links. The drag links are attached to the middle of the links, L, by the drag-link pins, D L P, and either eccentric-rod end may be brought to coincide with the centre-line of the valve-rod block. The various working brasses can be adjusted for wear. We have already described the construction and action of an eccentric, so that we need here merely draw attention to the figure of the *St. Rognvald's* eccentric. We would recommend the student to make a scale drawing (side and front view), connecting together, in their actual working position, the eccentric, strap, rod, link, valve spindle, and valve for the low-pressure cylinder of these engines, after carefully comparing the specification of the various parts with the working drawings given in this Lecture

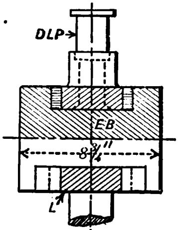
and Lecture XX., and then to make a working model, in metal or cardboard, to the size of his scale drawing, including the steam ports, so as to study the action of the link motion from actual observation.



INDEX.

L for Link bars.
E B ,, Eye blocks (fitting valve-spindle eye).

End View of Valve-spindle Eye Block.→



INDEX.

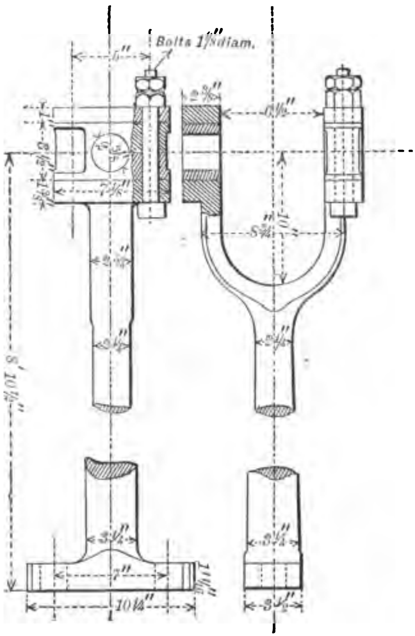
D L P for Drag-link pins.
E R P ,, Eccentric-rod (end) pins.

←Cross Section through Drag-link Pins.

S.S. "St. Rognvald's" Link-motion Bars and Valve-spindle Eye Block.

Specification for the s.s. "St. Rognvald's" Valve Motion.—To have double-bar link motion, each bar of which to be of mild steel, 1½ inch thick and 4 inches broad, with studs for upper ends of eccentric rods, 2⅜ inches diameter, 2½ inches long. The centre part to have a boss, 3 inches diameter and 2⅜ inches deep, for receiving drag-link pins, all forged on solid. Eccentric rods, 2¼ inches diameter at smallest part, tapering to 3¼ inches diameter at lower end, to have double jaws at upper ends with hard brasses and wrought-iron covers, and secured with steel bolts and double nuts. Lower ends to be ⊥-shaped, and secured to eccentric straps with steel studs and double nuts. Valve spindles to be of forged mild steel, 3½ inches diameter, with large eye at lower end, lined with hard brass for valve-link block (which is to be of cast steel with hard brass adjusting slips above and below link). To

have adjustable guides attached to under sides of valve casings, with rectangular hard brasses secured with wrought-iron covers and studs. Upper end of high-pressure cylinder valve rod to have brass dome guide. Upper end of low-pressure cylinder valve rod to have a balance piston and cylinder, 12 inches diameter, on top of valve-casing cover. Eccentric pulleys to be $3\frac{3}{4}$ inches broad, of cast iron, keyed on crank-shaft couplings, by single key with head, and steel pinching screws, and to have straps fitted to them made of gun-metal with cast-iron parting pieces, and secured with steel bolts and double nuts. Drag links to be of wrought iron (double), and made adjustable at all the working parts with hard brass bearings.

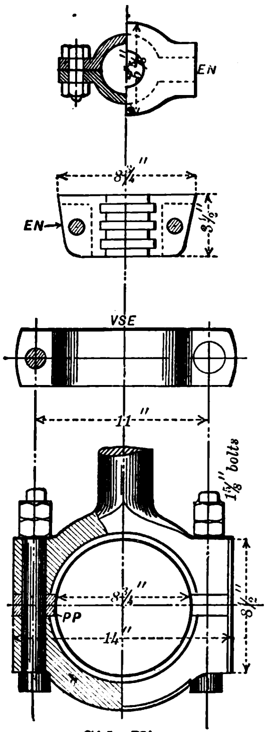


S.S. "St. Rognvald's" Eccentric Rods.

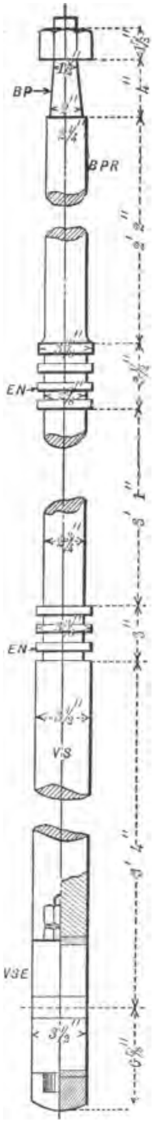
Eccentric Rods.—These rods are usually made of wrought iron, and separate from the eccentric straps, unless they are small or very short, when the strap and rod may be forged in one, with the latter lined inside with brass. The shank of the rod in the above illustration is round, and tapered from the ⊥ foot towards the U forked end. Eccentric rods are, however, frequently made rectangular in section, which is the natural form to resist the stresses; but they are more expensive to make, more troublesome to keep bright, and do not lessen the weight of the rods very much.

INDEX TO PARTS.

B P	for	Balance piston (cone).
B P R	„	Balance-piston rod.
V S	„	Valve spindle.
V S E	„	Valve-spindle eye.
E N	„	End nuts.
P P	„	Parting pieces, or stripping blocks.

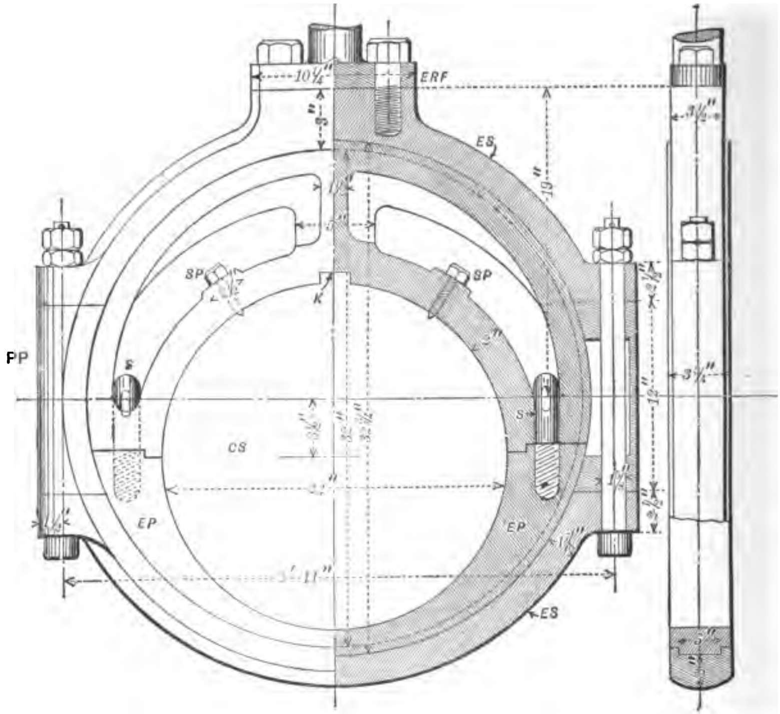


Side View.



End View.

S.S. "ST. ROGNVALD'S" VALVE SPINDLES.



Half Outside. Half Section. End Views.

S.S. "St. Rognvald's" Eccentric Pulleys and Straps.

Index to Parts

C S for Crank shaft.
E P ,, Eccentric pulley.
E S ,, Eccentric strap.
P P ,, Eccentric-strap parting, or stripping piece.

E R F for Eccentric-rod foot.
K ,, Eccentric-pulley key way.
S P ,, Eccentric-pulley set pins.
S ,, Studs and cotters for fixing halves of E P together.

Lecture XXIII.—Questions. *

1. In marine engines with large cylinders it often becomes necessary to diminish the travel of the slide valve, while keeping a considerable opening of the ports for the admission of steam. Sketch a section through a valve and ports, showing how this can be done, and put the valve in its position for the commencement of the stroke of the piston.

2. Describe the modified form of D slide known as a "double-ported" slide valve. Sketch a section through the valve and ports, showing the position of the valve when just opening for steam. When is it desirable to adopt a valve of this construction? (S. and A. Exam., 1887.)

3. Sketch, both in plan and section, a slide valve suitable for the low-pressure or intermediate cylinder of a large marine engine. You are required to show the contrivance at the back of the valve for relieving the pressure on its face.

4. Sketch and describe a piston valve. What are the reasons for adopting this form of valve in preference to ordinary slide valves? Explain its advantages and disadvantages.

5. Describe any form of valve suitable for an expansion valve, such as a gridiron valve in a condensing engine. Show the method of actuating such a valve, making any necessary sketches.

6. What is an expansion valve? Sketch such a valve, and show where it is placed with reference to the ordinary slide valve, and explain the manner in which it acts.

7. A marine engine is provided with an ordinary three-ported valve (the S. and A. examiner here means a valve like the s.s. *St. Rognvald's* high-pressure cylinder slide valve), but has a back cut-off valve for varying the grades of expansion. Sketch the combination in section, and explain its action.

8. What is the object of a separate expansion valve, and where is it placed? Sketch a section through a gridiron expansion valve. If such a valve has a travel of 1 inch, and the ports are 12 inches wide, how should the valve be constructed so as to give a maximum opening of ½ square foot? (S. and A. Exam., 1887.) *Ans.* Use 6 openings, each 1″ wide.

9. Sketch and describe some form of slide valve which is fitted with a variable expansion slide at the back. (S. and A. Exam., 1887.)

10. How is an engine reversed when fitted with a single eccentric which is not keyed to the driving shaft? (S. and A. Exam., 1887.) Sketch and describe the apparatus.

11. Sketch and describe Stephenson's Link Motion, and show how it works.

12. Sketch to scale the side and end views, and describe the construction and action of the low-pressure cylinder slide valve, valve spindle, link motion complete, with eccentric, strap, and rod, of the s.s. *St. Rognvald*, all connected together in proper working order.

13. Sketch and describe any form of balanced slide valve. What is the purpose of the arrangement? What is the advantage of a double-ported slide valve over one with single ports, and when would such a valve be used? (S. & A. Exam, 1892.)

14. Explain the manner in which a marine engine is reversed when fitted with a single eccentric sheave which can be shifted in position upon the shaft. (S. & A. Exam. 1892.)

* See Appendix for more recent S. & A. Questions.

LECTURE XXIV.

CONTENTS.—Condensers—Jet Condenser—Surface Condenser—Air Pump—Circulating Pump.

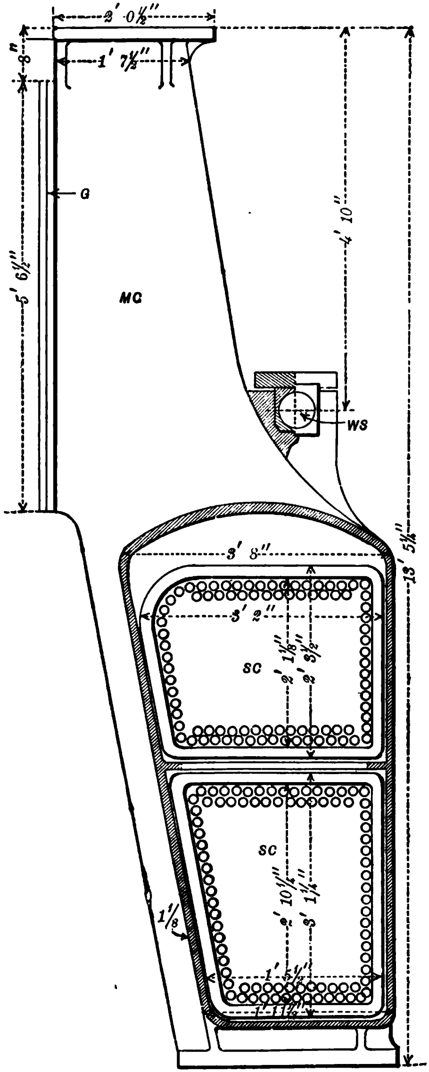
Condensers.—Condensers are of two kinds—*jet* condensers and *surface* condensers. In the jet condenser the steam is condensed by being brought into actual contact with cold water; while in the surface condenser the steam condenses upon thin metallic surfaces, which are kept cool by circulating cold water on the other side. In Lecture IX. we dealt very fully with the quantity of water required for condensing 1 lb. of steam by the jet condenser, so that we need not refer to this again.

*Jet Condensers.**—Jet condensers may be of almost any form which is suitable for the engines to which they are to be fitted. They consist essentially of a cast-iron chamber, in which the exhaust steam from the cylinder and cold water are freely mixed. The bottom of this chamber is connected to a pump known as the air pump, the function of which is to draw off the water and any air or vapour which may be in the chamber. The condensing chamber or condenser must be of sufficient capacity to prevent flooding—*i.e.*, becoming filled with water—but should not be larger than is absolutely necessary for the air pump to form a good vacuum after the engine starts. The bottom of the condenser should be inclined towards the side to which the air pump is connected, so that all the water may run into the suction end of the pump. The inlet for the steam should be high up in the condenser, and is usually a plain pipe. The water-injection inlet should be formed with a perforated pipe or rose, carried well into the middle of the condenser, or opposite the end of the steam pipe, so that the water may be fairly distributed, and the condensation of the steam be almost instantaneous. If the condenser is very large, or of a long shape, two rose injection pipes may be fitted with advantage. There is a small snifting or air valve opening outwards from the condenser fixed near the foot to facilitate blowing

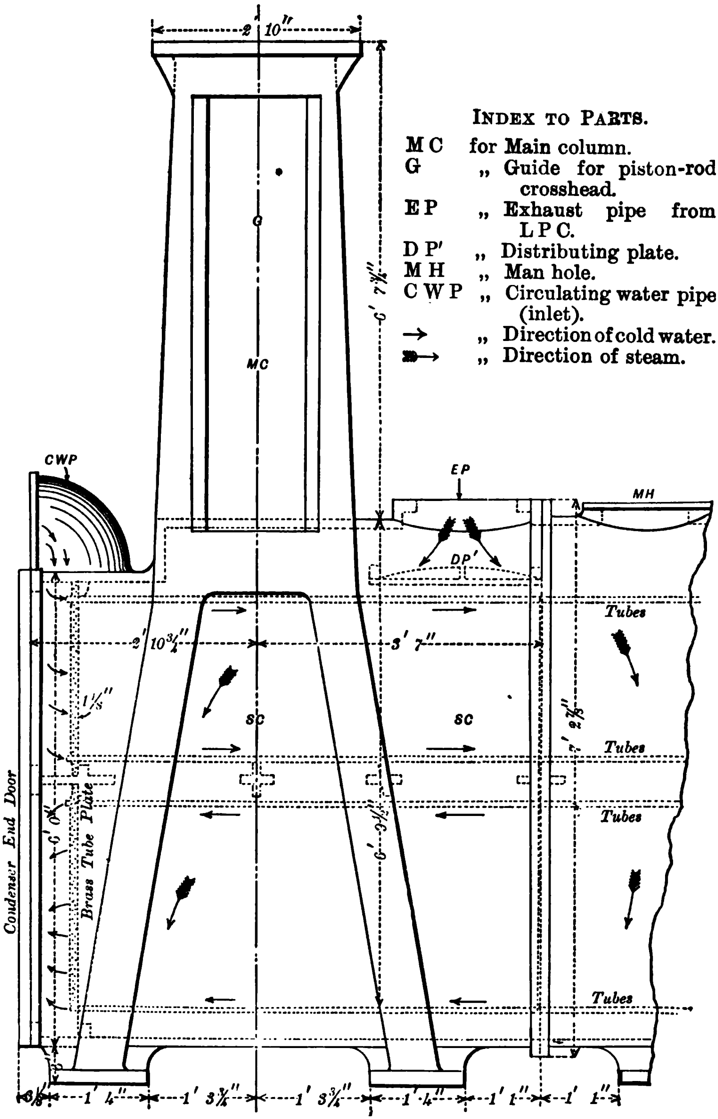
* See figures of Watt's Engines, Lecture XVIII., for positions and form of jet condensers; also the plans in Lecture XX., for C I P, the common injection pipe fitted into the exhaust pipe of the s.s. *St. Rognvald's* engines, which acts as a jet condenser.

through before starting the engines, and thus clearing out all air. It is imperative that all the joints should be thoroughly air-tight, otherwise a good vacuum cannot be maintained.

Surface Condenser.—The surface condenser, as usually made, consists of a cast-iron chamber, having a large number of thin brass tubes passing from one side or end to the other. These tubes are kept cold by forcing cold water through them by means of the pump known as the circulating pump. The exhaust steam, which is admitted into the condensing chamber, comes into contact with the exterior surface of the tubes, and is condensed by the cooling effect of the water they contain. In some few cases this order of things has been reversed, and the steam passed through the tubes while the cold water is circulated outside. "Baffle" plates are usually fitted immediately opposite the steam entrance, in order to distribute the steam evenly over the tubes. The condenser tubes are usually divided into groups or tiers. The cold water is forced through one tier of tubes, and then returned back across or along the condenser by another tier. The number of tiers is usually from two to four. The best method of working is to cause the hottest water to meet the hottest steam. Thus, if the steam enters at the top of the condenser, and the tubes are horizontal (as in most marine engines), the cold water should be forced in at the bottom, and passed first through the lowest group of tubes, returning along the group next above the lowest. The water is thereby considerably raised in temperature, and just previous to its being discharged from the condenser it passes through the highest group of tubes, which group is first acted upon by the steam. The condenser tubes are usually about $\frac{3}{4}$ inch outside diameter, and are of tinned brass. They are fitted into brass tube plates, and packed to prevent leakage. The methods of packing them are very varied, but one of the best which is in general use is worthy of notice, and is shown in the figure (p. 236), which represents the method adopted in the s.s. *St. Rognvald's* condenser. The brass tube plate, T P, is from 1 to $1\frac{1}{4}$ inch thick, and has holes bored in it to receive the tubes, T. These holes are bored $\frac{1}{4}$ inch (or a little) larger in diameter than the tubes, for about $\frac{3}{4}$ inch into the thickness of the plate, and are screwed so as to receive small brass stuffing glands, G—the diameter of the holes for the remainder of their length being only slightly larger than that of the tubes, to allow freedom for packing. Hemp or other suitable packing is wound round the tubes in the annular spaces between the tubes and the plate, and this packing is held firmly in position by the screwed glands. The glands are simply brass ferrules (screwed in long lengths from ordinary brass

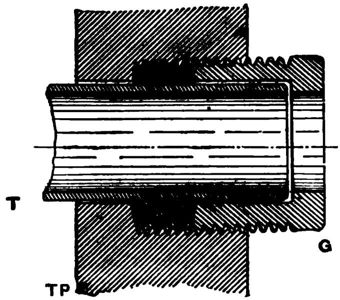


Elevation and Cross Section



Front Elevation.

tubing, cut off with a circular saw, and notched), which fit loosely on the tubes, and are screwed externally to fit the screwed hole in the tube plate. They have a slit on one end, so that they may be screwed home by means of a brace fitted with a screw-driver bit. When the condenser tubes are vertical, the glands are made as shown in the diagram, with a small internal flange or shoulder, to prevent any end movement of the tubes; but when the tubes are horizontal, this flange is frequently omitted.



CONDENSER TUBE PACKING.

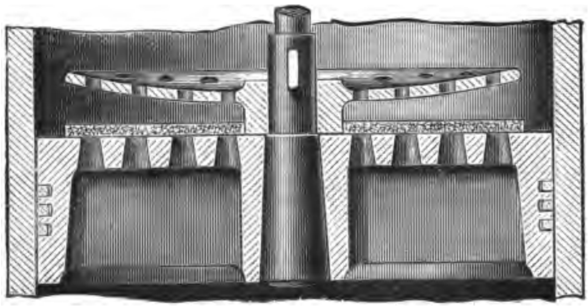
From what we have just said, and with the specification and "Index to Parts" which follow the illustration of the s.s. *St. Rognvald's* condenser, the student should have no difficulty in thoroughly understanding it.

Specification for the s.s. "St. Rognvald's" Condenser.—To be of the horizontal surface-condensing type, placed in a fore and aft position on port side of sole plate. The metal to be $1\frac{1}{8}$ inch thick, with strong ribs under columns, and the condenser to be well secured to sole plate and cylinders, with turned and fitted bolts and nuts. Tube plates to be $1\frac{1}{8}$ inch thick, of cast brass, and secured by brass bolts to condenser flanges. Tubes to be solid drawn brass $\frac{3}{4}$ inch external diameter, of number 18 B.W.G., except the two top rows, which are to be 16 B.W.G. All tubes to be tinned inside and outside, and to have a total condensing surface of 2800 square feet. The ends of the tubes to be packed with best red rubber rings, and so fitted as to provide for expansion and contraction. Brass stay plates, $\frac{5}{8}$ inch thick, to be fitted inside condenser where required, and secured by brass studs and nuts. Condenser to be fitted with spray pipes, so as to be able to work as a jet condenser if necessary. Doors to be fitted in top and bottom of condenser where required, for examining or cleansing it. Condenser end doors to be made in two pieces, each having snugs for lifting shackles, and sight doors 10 inches diameter opposite ends of tubes. A brass supplementary feed cock, 1 inch diameter, to be fitted to the condenser to admit circulating water.

With the surface condenser, the condensed steam, and consequently the feed water, are kept entirely separate from the circulating water, and only a very little salt water (or, better, fresh water from a separate condenser or fresh-water tank) has to be added by an auxiliary feed pipe, in order to make up for any leakage that may take place. A careful engineer has therefore little or no necessity for blowing off, and he can run his boilers for two months at a time without changing the water in them, or allow-

ing more deposit to accumulate than a thin skin less than the thickness of a sixpence, which is considered beneficial if evenly deposited, as it prevents pitting of the boiler plates.

Air Pump.—As we have remarked before, the duty of the air pump in the case of a jet condenser is to discharge the whole of the condensing and condensed water as well as the air into the hot well, and in the case of a surface condenser to free the same of the condensed water as well as the air and the vapour which have been set free. Water contains a large proportion of air mixed with it, unless it has been expelled by one or other of the special methods now adopted in connection with high-pressure engines. The air expands in the condenser, and would considerably diminish the vacuum, if it were not taken out at every stroke of the air pump. Besides this air, there would, of course, be an accumulation of vapour or low-pressure steam in the condenser, from the condensed water under the action of a partial



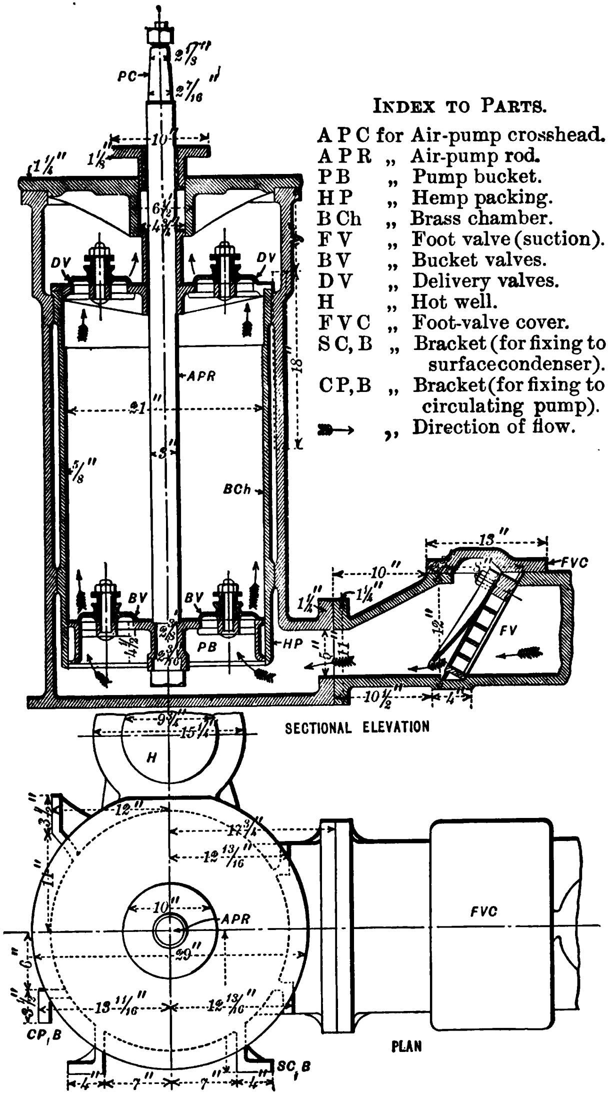
AIR PUMP BUCKET.

vacuum, and this vapour would soon fill the condenser and also spoil the vacuum, if it were not extracted by the air pump. Consequently, we see that the chief work which the air pump has to perform is to free the surface condenser of air and vapour, for a very small pump would suffice to extract the condensed steam. Care must, therefore, be taken not only to have a thoroughly efficient, but also a sufficiently large air pump, in order to maintain a good vacuum.

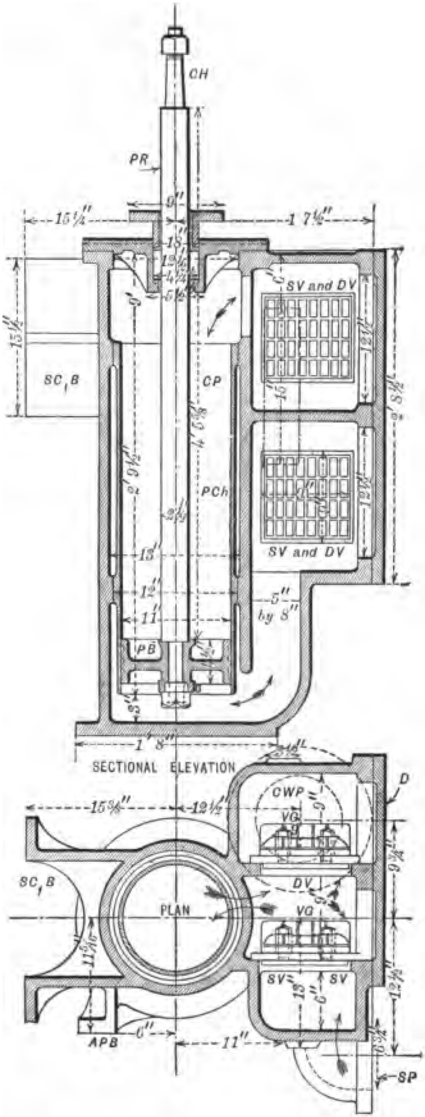
The above figure shows a vertical section through a small air-pump bucket. The pump rod is enlarged at its lower end and tapered to fit the bore of the boss. A tapered cottar through the rod secures the india-rubber and check valve in position. This bucket is packed with Ramsbottom rings in the same way as the box pistons shewn in Lecture XXI. The usual plan of packing—especially for large air pumps—is that indicated by the next figure; where the recess in the periphery of the bucket is filled

Index to Parts.

A P C for Air-pump crosshead.
A P R „ Air-pump rod.
P B „ Pump bucket.
H P „ Hemp packing.
B Ch „ Brass chamber.
F V „ Foot valve (suction).
B V „ Bucket valves.
D V „ Delivery valves.
H „ Hot well.
F V C „ Foot-valve cover.
S C, B „ Bracket (for fixing to surfacecondenser).
C P, B „ Bracket (for fixing to circulating pump).
➼→ „ Direction of flow.



S.S. "St. Rognvald's" Air Pump.



Index to Parts.

C H	for	Crosshead.
P R	,,	Pump rod.
C P	,,	Circulating pump.
P Ch	,,	Pump chamber.
P B	,,	Pump bucket.
S P	,,	Suction pipe.
S V, D V	,,	Suction and Delivery valves.
V G	,,	Valve guards.
C W P	,,	Circulating water pipe, or discharge pipe.
D	,,	Door to valve chamber.
A P, B	,,	Bracket (for fixing to air pump).
S C, B	,,	Bracket (for fixing to surface condenser).

S.S. "St. Rognvald's" Circulating Pump.

up to the bore of the chamber barrel with hemp yarn twisted into a firm square section and then wound tightly round the bucket.

Specification for the s.s. "St. Rognvald's" Air Pump.—To be 21 inches diameter and 28 inches stroke, worked by forged wrought-iron levers from the crosshead of after-engine. The brass chamber, B Ch, to be ⅝ inch thick; it, as well as the bucket, A P B, valves, B V and D V, seats, and air-pump rod, A P R, covering, to be all of cast brass. The foot valve, F V, to be placed clear of bottom of pumps for easy examination. Patent metallic valves, of approved make, to be fitted throughout, and a drain cock, 2 inches diameter, to be fitted to bottom of pump. A small air valve to be fitted to pump under discharge valves, D V.

Circulating Pumps.—Circulating pumps are only employed in connection with surface condensers. They are of three kinds—single, or double-acting reciprocating, and rotary pumps. The single-acting pump should be provided with a good-sized air vessel, about double the capacity of the pump, in order to cause a steady flow of water through the condenser tubes. It, as well as the double-acting one, should have a small inlet air valve or pet valve, so placed as to automatically admit a sufficient quantity of air to act as a cushion, and thus prevent the natural vibration and noise due to the momentum of the water; also a small pipe and cock, or bye-pass, connecting the suction and delivery chambers, to regulate the supply of water without putting any over-stress on the pump.

Specification for the ss. "St. Rognvald's" Circulating Pump.—The engines to be fitted with one double-acting circulating pump, C P, 11 inches diameter and 28 inches stroke, placed alongside of air pump, with cast-brass chamber, P Ch, and solid brass bucket, P B. Valve seats, S V and D V, and guards, V G, and pump-rod liner, P R, to be of cast brass, and valves of best red rubber. Pump to have a 5½" suction non-return valve, with pipe from engine-room bilge fitted with a lead rose box. All the bolts and nuts in and about these pumps and condenser which are exposed to sea water to be of brass. A small air valve to be fitted to each end of pump.

LECTURE XXIV.—QUESTIONS.*

1. What is surface condensation? Distinguish between a surface condenser and a jet condenser. Describe the method of carrying out each system of condensation, making any sketches you think necessary.

2. Sketch a section through a surface condenser, showing the passage of the water and steam through it. By what means is the flow of water kept up? (S. and A. Exam., 1887.)

3. Mention some of the advantages of a surface condenser as applied to marine engines, and draw in section a surface condenser, showing the mode in which water is caused to circulate through it. How are the tubes fitted so as to avoid leakage? How is the vacuum ascertained?

4. A surface condenser consists of 1000 brass tubes, each 6 feet long and $\frac{3}{4}$ inch outside diameter. What amount of cooling surface does this give? Supposing that such a surface condenser is to be fitted to an engine, what pumps, valves, &c., would be required, and how would you arrange them in order to put the apparatus into working order? *Ans.* 1178·5 sq. ft.

5. A surface condenser has 1725 tubes, each $6\frac{1}{2}$ feet long and $\frac{3}{4}$ inch outside diameter, what amount of condensing surface do they give? Write down two numbers which express pretty nearly the relative conducting powers of copper and iron. How are the condenser tubes usually fitted and kept tight? *Ans.* 2202 sq. ft.

6. A surface condenser has 900 tubes, $\frac{5}{8}''$ internal diameter, $\frac{1}{16}''$ thick, and 6′ 6″ long. Find the cooling surface in square feet. *Ans.* 1149 sq. ft.

7. A boiler has a heating surface of 1230 square feet. The cooling surface of the condenser is required to be 90 per cent. of the heating surface of the boiler. How many tubes $\frac{3}{4}''$ external diameter and 9′ 4″ long will be required? *Ans.* 604.

8. If the thickness of the tubes in the last question be $\frac{1}{16}$ inch, find the weight of the tubes and the weight of water to fill them. (Here refer to Table at the beginning of Lecture III.) *Ans.* 1388 lbs.; 751 lbs.

9. Sketch a section through a single-acting vertical air pump, showing the construction of the bucket and also the position and construction of the valves.

10. Sketch a section through the air pump and condenser of a condensing engine; name the several valves and essential parts, and point out their uses. Show the construction of the valves. (S. and A. Exam., 1888.)

11. Sketch a section through a double-acting circulating pump for marine engines, and describe its action and give a complete index to parts.

12. Marine engines are fitted with a so-called air pump, circulating pump, feed pump, and bilge pump. What are the respective uses of these pumps? Show, with a sketch, the construction of any one of them, and explain how it acts. (S. and A. Exam., 1889.)

13. Sketch a section through a vertical air-pump, together with the foot and delivery valves. The bucket plunger has a valve in it, describe the construction of the valve and the packing of the plunger, and show by your drawing the method of attaching the pump rod to the bucket. Which valves are open during the descent of the bucket? (S. & A. Exam. 1890.)

14. Sketch a sectional elevation of a double-acting air-pump with foot and delivery valves, such as is suitable for a direct-acting engine. Describe clearly the construction of an india-rubber disc valve. (S. & A. Exam. 1891.)

* See Appendix for more recent S. & A. Questions.

LECTURE XXV.

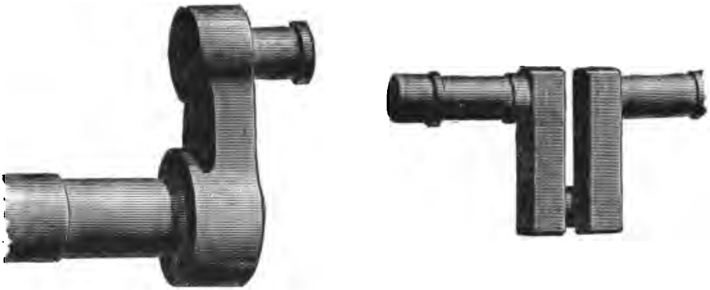
CONTENTS.—Crank Shafts—Thrust Shaft, Block, and Bearing—Intermediate Screw Shafts—End Screw Propeller Shaft—Stern Tube—Ordinary Form of Screw Propeller.

Crank Shafts.—As explained in Lecture XIV., the crank of an ordinary steam engine enables the reciprocating to-and-fro motion of the piston in the cylinder, to be converted into the circular motion of the crank shaft through the intervention of the piston rod and connecting rod. In the case of land engines employed to drive in factories and workshops, the power developed in the cylinder and transmitted to the crank shaft is usually conveyed to the shafting by means either of a spur wheel keyed to the crank shaft, or by a flat pulley with belting, or by a WW grooved fly wheel and rope drive. In marine paddle engines the crank shaft is invariably connected direct to the paddles, and in screw engines through intermediate shafting to the screw. In locomotives, the crank shaft is connected direct to the driving wheel. In the case of engines for driving dynamos, the power may be transmitted by pulley and belting, or the crank shaft may be coupled direct to the dynamo spindle, when high-speed engines are employed. Whichever plan be adopted, the main object aimed at is to transmit the power developed in the cylinder as direct and undiminished as possible to the machinery.

Crank shafts are subjected to bending and twisting stresses, and must be made sufficiently strong to withstand these, as well as stiff enough not to spring and heat the bearings. Any remarks in an elementary treatise like this must be confined to merely describing the different forms of crank shafts, leaving an investigation of their dimensions to our more advanced courses of Steam and Applied Mechanics.

Single-cylinder land engines have but one crank, which is fixed either at the end of the shaft, as shown by the first figure, or with two crank webs and outer and inner bearings, as shown by the second figure.

Locomotive crank shafts for outside-cylinder engines simply consist of plain shafts, keyed firmly into the driving wheels at each end —the crank pins being fixed into solid bosses in the wheel at the



BESSEMER STEEL CRANK SHAFTS FOR LAND ENGINES.

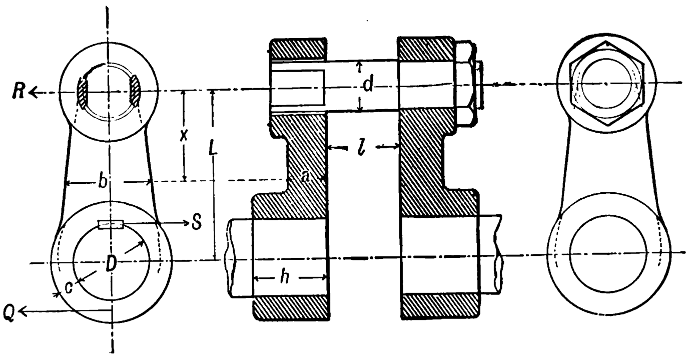
proper radius from the crank-shaft centre for the piston's stroke. Inside-cylinder engines are fitted with cranks of the shape shown by the following figure, and the crank webs are generally fitted with weldless-steel or iron hoops, shrunk on to them, so as to strengthen them, and to prevent their coming to pieces and doing damage, should they crack or break through the neck.

BESSEMER STEEL CRANK SHAFT FOR LOCOMOTIVES WITH INSIDE CYLINDERS.

Small launch engines or fast-speed electric-light engines are often fitted with very strong crank webs, as shown by the following figure.

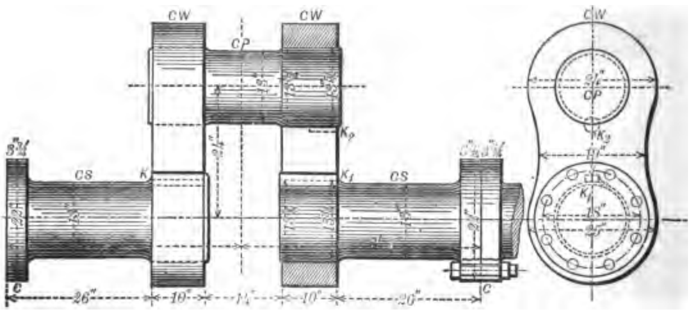
CRANK SHAFT FOR LAUNCH ENGINE.

Marine paddle-wheel engines have their cranks usually arranged as shown by the following figure, taken from Seaton's *Marine Engineering*.



CRANK SHAFT FOR PADDLE-WHEEL MARINE ENGINE.

Marine screw engines are usually fitted with two interchangeable crank shafts. Up to 12 inches in diameter, the crank and the shaft are generally forged or compressed in one piece, but above that size they are frequently made as shown in the following figure. Where lightness combined with strength is desired, they are made hollow. (See p. 29 for figure of crank shaft for s.s. *City of Rome*.)



Longitudinal View. End View.

S.S. "ST. ROGNVALD'S" CRANK SHAFT.

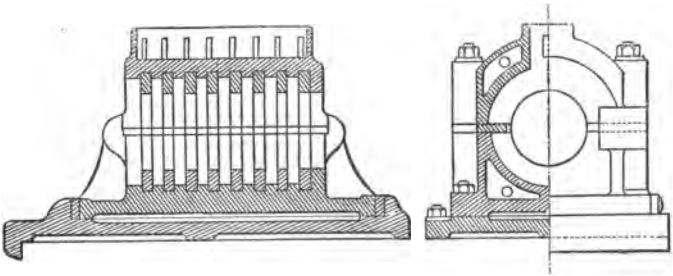
INDEX TO PARTS.

C S for Crank shaft.	C for Couplings.
C P ,, Crank pin.	K_1 ,, Key (web to shaft).
C W ,, Crank webs.	K_2 ,, Key (web to pin).

Specification for s.s. "St. Rognvald's" Crank Shaft.—Crank shaft to be built of best forged mild steel, made in two pieces, interchangeable and reversible, bolted together with bolts 2¼ inches diameter. Crank webs to be 10 inches thick, and carefully shrunk on shafts and crank pins, and keyed upon shafts with steel keys 1¾ inch deep, 2½ inches broad. Crank-

pin bearings to be 14 inches long, and 13 inches diameter; and crank-shaft bearings 18 inches long, and 13 inches diameter. The whole of the bearing parts to be turned perfectly true, after being fitted together, and the finished shaft to be carefully fitted into its bearings.

Thrust Bearings and Shaft.—In marine screw engines it is necessary to provide some means of taking up the longitudinal thrust of the screw propeller. In small engines this is often done by a simple collar on the shaft, which bears against the flange of the aft main bush in the sole plate; but when the thrust is great, this plan is not sufficient, and a "thrust block" is fitted. The form of thrust block which was chiefly in use until recently is shown in the following figure. An enlarged portion of the screw shaft next to the crank shaft has a number of rings cut in it, and these rings fit into corresponding recesses in a large brass bush. These recesses are formed either by having rectangular grooves bored out of the brass or by the insertion of brass rings into checks bored out to receive them, as shown in the figure. This



COMMON SMALL THRUST BLOCK.

arrangement has been found to work very well for small sizes, and when effectually prevented from heating. When it heats it gives great trouble, and adjustment cannot very well be effected at sea.

A much better form of thrust block, T B, is shown in the next figure. In this block, the thrust is supported by independent horse-shoe shaped pieces of cast iron, H S, which are faced with white metal. These thrust pieces fit between rings, C_1 to C_5, turned on the screw shaft. They are secured on each side of the shaft to the thrust block, but are capable of independent adjustment by means of the nuts and set screws, A S, on each side, or, of adjustment as a whole, by the nuts at each end of the rods which support them at the sides. This block has some advantages over the old form, the principal of which are—(1) The horse-shoe pieces are separate and independent of each other, and they may be adjusted, or taken out separately for examination, without stopping the engines. (2) The lubrication is more easily effected, since the hollow casing

of the thrust block below the shaft may be filled with oil and soapy water poured in through the oil cups, O C. The rings on the shaft revolve in this mixture, and thus every part of the bearing is kept continuously lubricated with little attention and trouble.

A thrust bearing, of course, affords no lateral or vertical support to the shaft; its office is simply that of taking the end thrust and transmitting it to the whole ship. Consequently the shaft should always be supported close to the thrust bearing by an ordinary pillow block, or bearing, such as OB, shown in the figure.

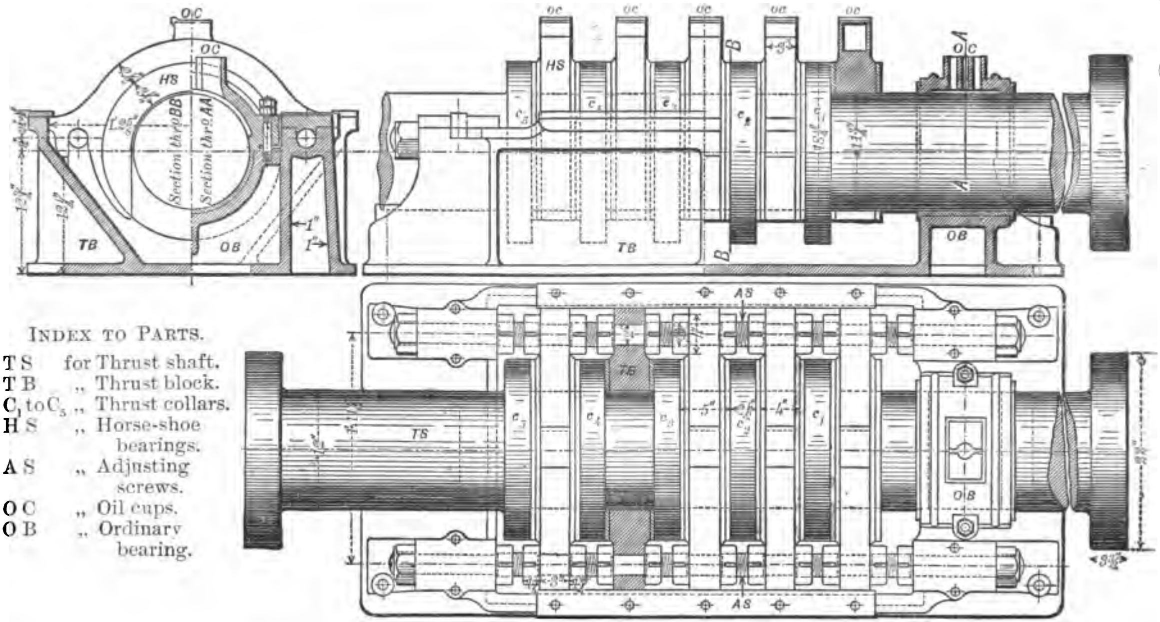
Specification for s.s. "St. Rognvald's" Thrust Bearing Block and Shaft.—To be a strong casting of iron, fitted with 5 cast-steel horse-shoe pieces, faced with approved white metal, and finished $\frac{1}{16}$ inch above the surface of cast steel. Each horse-shoe piece to be independently adjustable in a fore-and-aft direction on 2 mild steel rods $1\frac{1}{8}$ inch diameter, with brass adjusting nuts. The sole of block to have $4\frac{1}{2}$ feet of bearing fore and aft and 3 feet athwart ships, securely fastened with turned and fitted bolts, and nuts, to a very strong wrought-iron stool, worked on to ship's floors and keelson, the rivet holes of which are to be all rimered perfectly fair before riveting. A large box to be formed at bottom of bearing, with a drain cock and pipe led through water-tight bulkhead. A large oil box and water cock to be fitted to each collar. The thrust shaft to be made of best selected scrap iron $12\frac{1}{2}$ inches diameter, and not more than 12 feet long, with 4 solid collars $18\frac{3}{4}$ inches diameter outside, and $2\frac{1}{2}$ inches thick.

Intermediate Screw Propeller Shafting.—These are simple plain shafts with large couplings at each end, of the shape shown in Lecture III., p. 23, Example VII., properly supported at suitable intervals by ordinary bearing blocks.

Specification for s.s. "St. Rognvald's" Intermediate Shafts.—To be forged of best selected scrap iron, $12\frac{1}{2}$ inches diameter, turned all over, made with solid couplings, and secured with well-fitted bolts and double nuts. Bearings, lined with approved white metal, to be supplied for shafting in tunnel, where required, each fitted with a water cock and tallow box on top, and saucers below the fore and after sides of each bearing. Wrought-iron stools to be made for the support of each bearing properly secured to ship's floors.

End Screw-Propeller-Shaft, Stern Tube, and Propeller.—This shaft is the tail or end shaft, and carries the screw propeller. In rough weather, it is subjected to very severe bending and twisting stresses; for in addition to the ordinary twisting stress due to the power of the engine forcing it round, and the bending stress due to its own weight and that of the screw, the pitching of the ship brings into play extra bending stresses.

The usual method of securing this shaft to the screw propeller in mercantile steamers, and the way in which the shaft is supported by the stern post and after-bulkheads, will be most easily understood by referring to the following figure and index to parts, as well as the specification of the s.s. *St. Rognvald's* propeller-shaft, stern tube, and propeller.



S.S. "ST. ROGNVALD'S" THRUST SHAFT AND BEARING BLOCK.

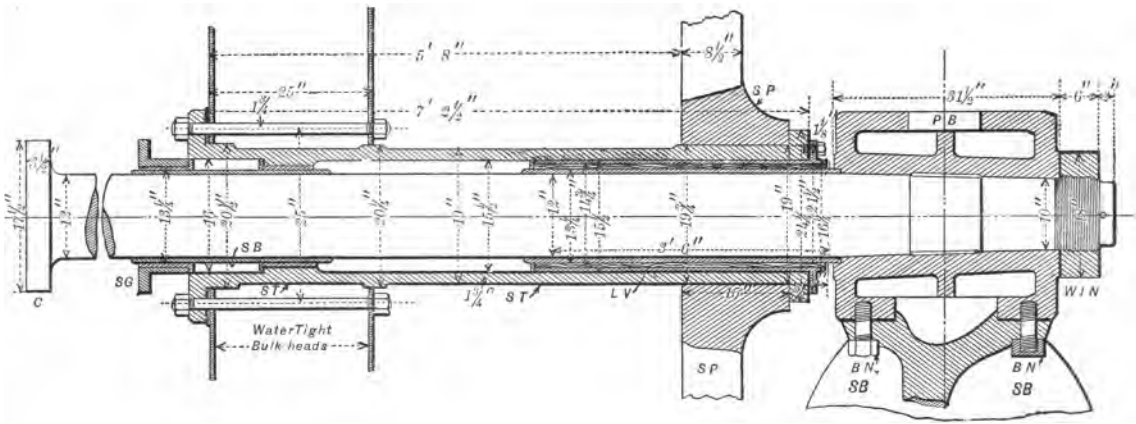
Specification for s.s. "St. Rognvald's" Propeller Shaft.—To be of best forged mild steel $12\frac{1}{2}$ inches diameter, and covered with brass liners $\frac{3}{4}$ inch thick, for stern-post, S P, and stuffing-box, S B, bearings.

S.S. "St. Rognvald's" Stern Tube.—The stern tube, S T, to be of very strong cast iron $1\frac{3}{4}$ inch thick, firmly secured into stern post, S P, and fastened with a strong wrought-iron nut, A, outside. To have a brass bush at outer end 3 feet 9 inches long, lined with staves of lignum-vitæ, L V, and fastened into the tube with an outer flange and 6 brass screw pins $1\frac{1}{4}$ inch diameter. Inner end of tube to have a stuffing box, S B, 12 inches deep, with brass neck ring 10 inches deep. The gland to be bushed with brass, and to be secured with 6 brass studs $1\frac{1}{4}$ inch diameter, having brass nuts. Two of these studs to be long enough to admit of stuffing box being packed.

S.S. "St. Rognvald's" Propeller.—Propeller boss, P B, to be of very strong cast iron, and fitted with four removable blades of mild cast steel, each of which is to be fastened to the boss with flanges 29 inches diameter, $2\frac{3}{8}$ inches thick, by 9 mild steel studs $2\frac{1}{8}$ inches diameter. The studs to be fitted with brass nuts, B N, capped, and each provided with a brass pinching pin, to prevent slacking back. The after-end of shaft to be tapered $\frac{3}{4}$ inch to 1 foot, and boss secured to it with a key the whole length of boss ($2\frac{1}{2}$ inches broad by $1\frac{1}{4}$ inch thick), and a strong wrought-iron nut, W I N, with a steel cotter pin put through point of shaft to prevent the nut slacking back.

Screw Propeller: Ordinary Form.—We do not happen to have received drawings of the s.s. *St. Rognvald's* complete screw propeller, but the following figures represent one so very like it that, by studying the same, along with the above specification and drawing, the student will have no difficulty in understanding the general arrangement and construction of an ordinary four-bladed screw, as used in mercantile steamers—referring to our more advanced text-book for a description of other forms, and the way in which they are constructed and proportioned.

The propeller boss, P B, is usually of cast iron and spherical in form, and has four recesses in it to receive the blades, B. The hole in the boss for the reception of the screw shaft is tapered, and the boss is fixed to the shaft by one or two long keys or feathers which are sunk into the shaft, and fit a key-way in the boss. The boss is prevented from being drawn off endwise by a large nut, which nut is of opposite pitch to the propeller, and usually has a small tapered pin behind it, which passes through the shaft and prevents the nut from slacking back. This nut is sometimes preserved from the corrosive action of the water by a brass or gun-metal cap, C, which is fixed to the boss, as shown in the drawing. The boss is usually forced tightly on the screw shaft by hydraulic pressure or ramming, before the nut is screwed up. The blades of the screw are formed with flanges on their inner ends, and these flanges are faced and bolted in to the recesses formed to receive them in the boss. The holes in the flanges of the blades are not round, but are elongated, as is shown on the drawing, so that each blade may be turned round a little, and its



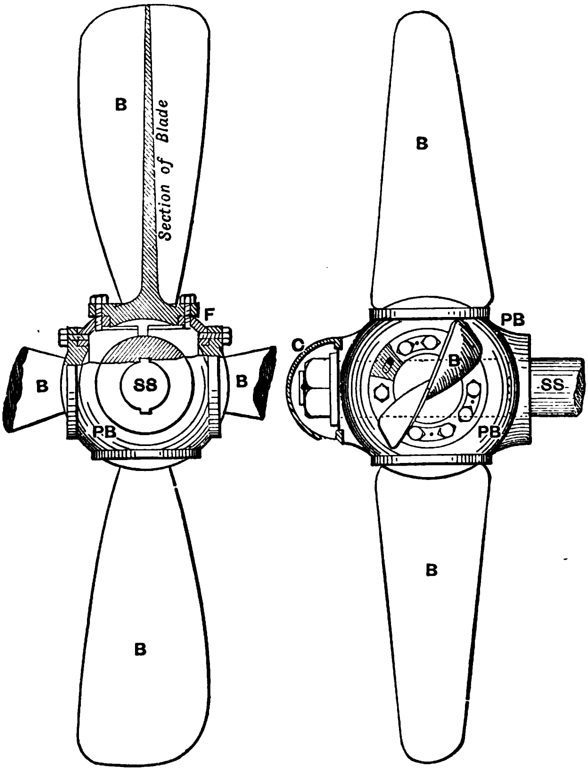
S.S. "ST. ROGNVALD'S PROPELLER SHAFT, STERN TUBE, AND PROPELLER BOSS.

INDEX TO PARTS.

C for Coupling.	L V for Lignum vitæ (bearing).	P B for Propeller boss.
S T „ Stern tube.	S P „ Stern post.	S B „ Screw blade.
S B „ Stuffing box.	A „ Stern-tube nut.	B N „ Brass nuts.

W I N for Wrought-iron nut on shaft.

pitch altered slightly if required. The spaces between the bolts and the ends of the holes are filled in with small pieces of brass or lignum-vitæ, to prevent the blade from shifting after the pitch has once been adjusted. Thin wrought-iron plates, fixed down by a small screw pin, are fitted between the nuts which hold down



ORDINARY SCREW WITH FOUR BLADES.

INDEX TO PARTS.

P B for Propeller boss.	S S for Screw shaft.
B ,, Blades.	C ,, Cap for protecting nut.
F ,, Flanges.	

the blades, so as to prevent the nuts from turning. In moderate sizes of screw propellers, the boss is always cast along with the blades; and since there are no nuts or projections on it, it offers

less resistance to the water than when the blades and the boss are separate. In the drawing of the screw propeller, the flanges of the blades are shown projecting above the general outline of the boss; but this need not be the case, since the flanges may be rounded on the top and recessed down flush with the boss, with the nuts also recessed into the flange of the blade. In the best practice large screws are made with a neat metal cap so fitted and fixed to the flanges of the blades as to cover-in the heads of the nuts and studs; or, as is sometimes done with cheaper propellers, the projecting angles of the flanges and nuts are smoothed over with a strongly adhering kind of plaster, which resists the action of sea water and prevents corrosion. The great advantage of constructing the screw with the blades separate from the boss is, that if one of the blades should be damaged, it may be replaced without the expense of an entirely new screw, and without the necessity of taking the ship into dock in order to have the boss forced off. It has, however, been adopted for large vessels only, since it is much more expensive.

LECTURE XXV.—QUESTIONS.

1. Sketch and describe the crank shaft for an ordinary single-cylinder land engine, and explain how the power of the engine is transmitted to the machinery which it has to drive.

2. Sketch and describe the crank shaft for a locomotive with inside cylinders. Why are the crank webs frequently fitted with a strong hoop shrunk on to them?

3. Sketch and describe the crank shaft for a large marine engine. Why are large crank shafts made in different pieces, and how are these put together and fixed?

4. In what way is the thrust of a propeller shaft communicated to the vessel? Explain your answer by sketches.

5. Sketch and describe, by an index of parts, a modern screw propeller shaft thrust bearing. Explain how the parts may be adjusted at sea, and state why another ordinary bearing should be placed near it.

6. Sketch and describe, by an index of parts, a complete line of screw propeller shafting, with the stern tube and screw complete. Be particular in showing the position, fixing, and form of the various bearings, and explain how the thrust of the propeller is imparted to the ship.

7. Sketch and describe, by an index of parts, an ordinary modern four-bladed screw propeller. How may a blade be replaced by a new one without unshipping the propeller? How can the pitch of a blade be altered within limits, and of what advantage is this device to the engineer?

8. The stroke of a direct acting engine is 5 feet and the crank shaft makes 30 revolutions per minute, find the mean speed of the piston in feet per minute. State your reasons for concluding that there is no loss of work from the oblique action of the connecting rod during successive portions of the stroke. Friction is neglected. (S. and A. Exam. 1889.) *Ans.* = 300 ft. per minute.

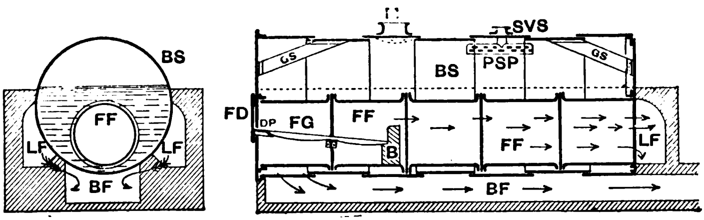
See Lecture XVII. of the Author's Advanced Text Book on "Steam and Steam Engines," by the same publishers.

LECTURE XXVI.

Contents.—Cornish Boiler—Lancashire Boiler—Marine Boilers.

All that the first-year or elementary student can be expected to know about boilers is the general form of the well-known Cornish and Lancashire land boilers, a modern marine boiler, and a locomotive boiler, together with their most necessary fittings. This Lecture will, therefore, be devoted to a description of the three first-named kinds of boilers and a few of their mountings.

The Cornish Boiler.—The simplest, and at the same time, one of the most common forms of land boiler for small powers, is that known as the "Cornish" boiler, from the fact of its having been first used to generate steam for the pumping engines used in the Cornish mines. The following diagram shows a longitudinal and a cross section through a Cornish boiler as now commonly constructed :—



Cross Section. Longitudinal Section.

Cornish Boiler.

Index to Parts.

B S	for Boiler shell.	L F	for Lateral or side flues.
F F	,, Furnâce flue.	B F	,, Bottom flue to chimney.
F G	,, Fire grate.	G S	,, Gusset stays.
D P	,, Dead plate.	M	,, Man hole.
B	,, Bridge.	S V S	,, Safety-valve seat.
F D	,, Fire door.	P S P	,, Perforated steam pipe.

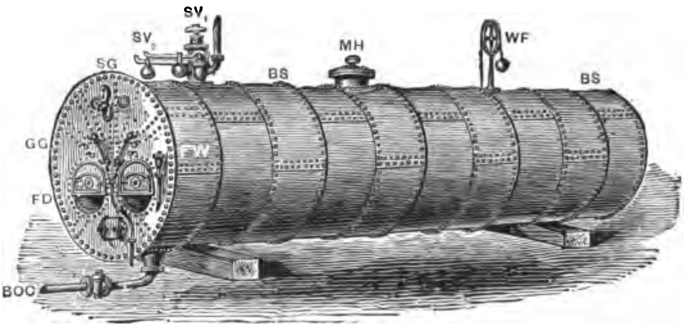
The products of combustion pass from the fire grate through the flue to the back end of the boiler, where they divide and return to the front end along the two lateral or side flues. At

the front, the products of combustion pass down to the bottom flue, and re-uniting move off to the chimney in contact with the bottom of the boiler. By this arrangement the gases are reduced in temperature before coming into contact with the bottom of the boiler, where all sediment collects, and there is, therefore, no danger of burning the plates on the under side of the boiler. Sometimes the gases are discharged direct from the furnace flue into the lower flue; but, unless in the case of very long boilers, where the gases may be considerably cooled before leaving the furnace flue, or where the water is very pure, this plan is objectionable, since the underneath plates on which sediment accumulates are liable to get burned.

The furnace flue in this boiler is welded at the longitudinal joints, and the several rings are joined together by flanged joints. It is attached to the front end plate by an outside angle iron ring, and to the back end plate by an inside angle iron ring, whilst these end plates are stayed to the shell by gusset plates. The furnace bars are made in two lengths, and are supported at mid-length by a cross bearer. At the front end these bars rest upon the dead plate, and at the back end they are supported by the fire-brick bridge. When air is admitted to the furnace flue at the bridge, a cast-iron stool usually supports the furnace bars and the fire-brick, and a suitable sliding door is fitted to the stool, the opening of which for the admission of air is controlled from the furnace mouth. As a rule, however, the whole of the bridge is constructed of fire-brick. The external flues are built of ordinary bricks, but are always lined in the inside with fire-brick.

The arrangement of the mountings and fittings, and the way in which the feed water is introduced, are similar to those in the Lancashire boiler, and therefore we need not repeat them here, as well as further on.

Lancashire Boiler.—The Cornish boiler is only suitable for small powers. When great power is required from any one boiler, that boiler, if made of the Cornish type, would require to have an excessively large furnace flue, in order to give sufficient grate surface. The length of the grate cannot be increased beyond that which can be conveniently worked by the fireman, and in practice it is usually from 5 to 7 feet. A flue of large diameter is weak to resist collapse, unless made of very thick plates, which is undesirable; hence, when great horse-power is required, the construction of the boiler is modified, and two flues of moderate size are fitted instead of one. This forms what has been termed the Lancashire boiler. In every other respect it is exactly the same as the Cornish boiler. The following diagram shows a complete Lancashire boiler, with all the necessary fittings.



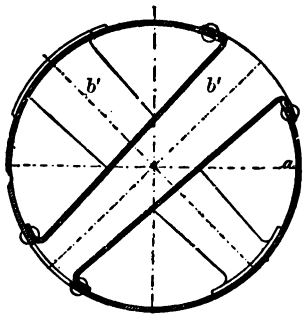
LANCASHIRE BOILER BY MESSRS. A. SHANKS & SONS.

INDEX TO PARTS.

B S	for Boiler shell.	W F	for Water float.
F D	„ Furnace doors.	S G	„ Steam gauge.
M H	„ Man hole.	G G	„ Gauge glasses.
SV_1	„ Stop valve.	F W	„ Feed-water cock.
SV_2	„ Safety valves.	B O C	„ Blow-off cock and pipe.

In the Lancashire boiler the furnaces are usually fired alternately, so that while the one is giving off smoke and unburnt hydrocarbon gases, the other is burning briskly, and with its greatest heating effect. By this arrangement, when the gases from the two furnaces mix in the external flues, the unburnt gases given off by the green fire (due to want of air and too low a temperature) are burnt by the excess of air which has passed through the other furnace, being raised to the point of ignition by the great heat of the gases from the bright fire.

Water Tubes.—In order to increase the effective heating surface and promote a better circulation of water, the flues of Cornish and Lancashire boilers are often fitted with water tubes. These water tubes are either parallel or tapered; the tapered tube, which is the better form, being known as the "Galloway" tube, from the name of the inventor. The annexed diagram shows the construction of these tubes, and the method of fitting them into the flues. The hole in the upper side of the flue

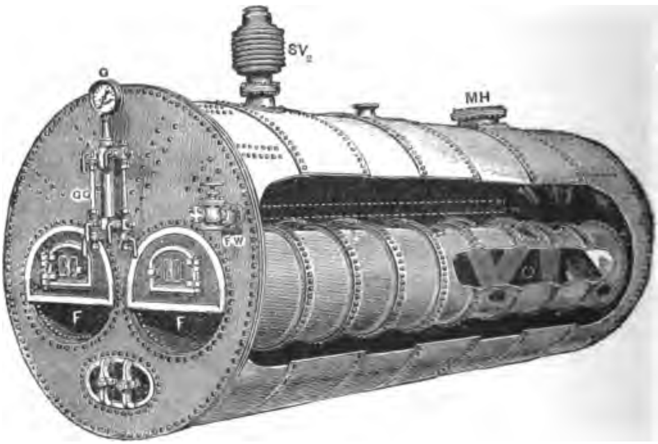


GALLOWAY TUBES.

is sufficiently large to allow the flange of the small end of the tube to pass through it, and the tubes are riveted to the flue in the manner shown. When parallel tubes are used, they are riveted to the flue with both flanges inside. These water tubes are very often welded into the flues, and this plan entirely prevents leakage at the joints, but if any tube fitted in this way requires to be replaced it must be cut out, and the welded part cut out with it, which leaves a very large hole in the flue.

Water tubes of this kind, besides increasing the heating surface and inducing circulation, act as stays and thus increase the strength of the flues in a very material degree.

From the following figure and the two previous ones, it will be seen that the fittings and mountings, such as the furnace doors, man holes, stop valve, safety valve, steam gauges, water-gauge glasses, feed-water and blow-off cocks, which require more or less frequent attention, are all placed outside the boiler, in the



LANCASHIRE BOILER BY MESSRS. DAVEY, PAXMAN, & CO.

most handy positions. In this figure there is shown, besides an outside view, a perspective view of the interior of the boiler, which gives a very good idea of how the internal flues are fitted, as well as of the diagonal water-tubes just referred to. It will be observed by the dotted white lines, leading horizontally from the feed-water cock, FW (situated on the right-hand side of the front end, and about two-thirds from the bottom of the boiler), that the feed-water pipe extends for a considerable distance inside the boiler, and that it is a perforated pipe. The reason for introducing the feed water in this manner and position, is to prevent

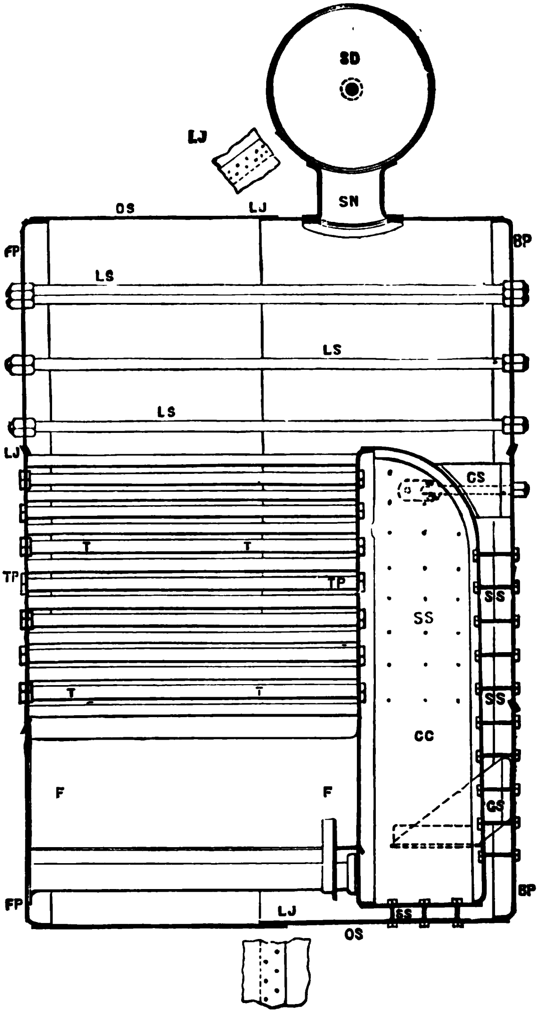
local contraction in the flues or boiler shell. The feed water, whether supplied from the hot well of a condensing engine, or direct from a cold-water tank, is considerably lower in temperature than the plates of the boiler at these places. Consequently, if this water were introduced, say, at the bottom of the boiler, or close to the tops of the furnace flues, it would cool these parts and cause them to contract, thus bringing an undue and unnecessary stress on those parts where it first impinged. The object, therefore, of the arrangement, as shown, is to prevent these stresses as far as possible, and to gradually introduce the coldish feed water through a series of perforated slits in the feed-water pipe along the line of the boiler not far under the water surface, and as far from the boiler plates as possible.

Marine Boilers.—Modern steam boilers which have to resist very high pressures have their shells made cylindrical, since that is the only form for which staying is not necessary, and the flues are also made of this form. Cylindrical marine boilers are made either single or double ended—*i.e.*, the boiler is fired from one end or from both ends. The former contain from one to four furnaces, and the combustion chambers are variously arranged.

The following illustrations represent the boilers of the s.s. *St. Rognvald,* constructed to supply steam to the engines of this steamer, which were illustrated and described in Lectures XX. to XXV.

There are two cylindrical, multitubular boilers, as shown, fired from one end, with four furnaces in each. The boilers are made of mild steel, with the exception of the tubes. Each boiler is 15 feet extreme diameter, and 10 feet 5 inches long. The plates are $\frac{7}{8}$ inch thick, in two lengths fore and aft. The circumferential seams are lap-jointed, and double riveted with rivets $1\frac{1}{8}$ inch diameter, and $5\frac{1}{4}$ inches pitch; the longitudinal seams are made with double butt-straps $12\frac{1}{4}$ inches broad, $\frac{3}{4}$ inch thick, and double riveted with rivets $1\frac{1}{8}$ inch diameter and 5 inches pitch. The end plates are $\frac{25}{32}$ inch thick, flanged all round, and double riveted to shell. The whole of the rivet holes were drilled 1 inch diameter before the plates were bent, and after being bent they were fitted together and the holes drilled out in place to fit the rivets. The edges of plates were planed all round, and the seams of shell were carefully caulked inside and outside. A baffle plate is fitted to the fronts of each boiler *above* the tubes.

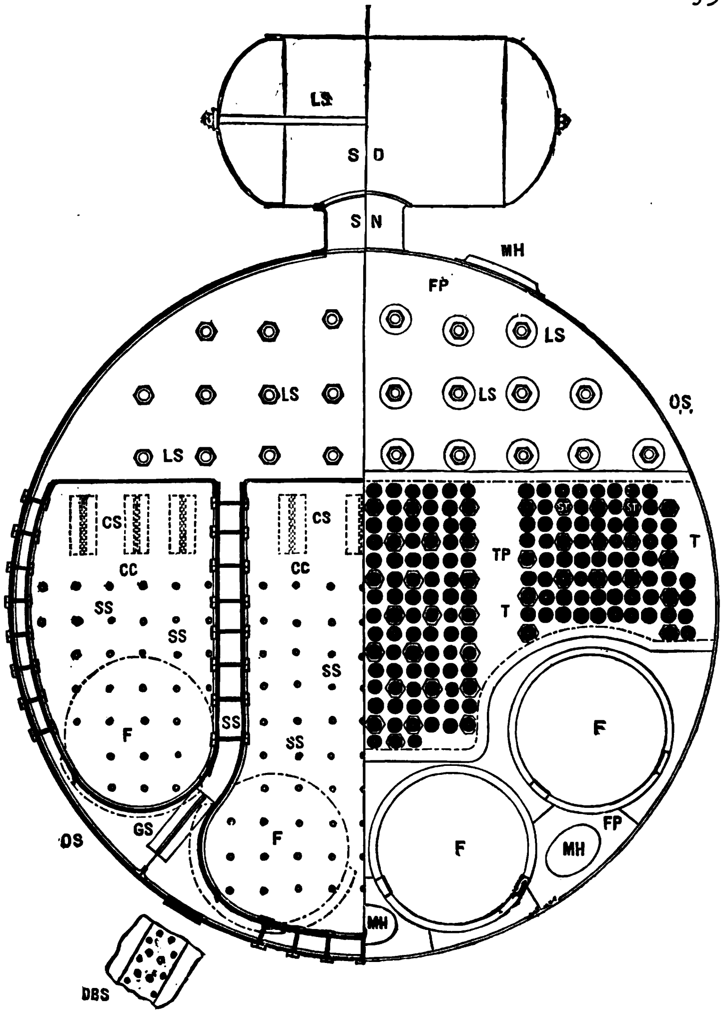
The furnaces for each boiler are 3 feet 4 inches outside diameter, and 7 feet long, of plates $\frac{9}{16}$ inch thick, the top plate being in one piece and jointed to the bottom plate by double butt straps $\frac{3}{8}$ inch thick and single riveted. The whole of edges of the plates and butt straps were planed and caulked outside and inside. The two



LONGITUDINAL SECTION.—SCALE, ¼ INCH = 1 FOOT.

INDEX TO PARTS.

O S for Outside shell.
F ,, Furnaces.
C C ,, Combustion chambers.
T ,, Tubes.
F P ,, Front-end plate.
T P for Tube plates (front and back).
B P ,, Back-end plate.
L J ,, Lap joint, in circumferential seams.



HALF-END VIEW AND CROSS SECTION.—SCALE, ¼ INCH = 1 FOOT.

INDEX TO PARTS.

D B S	for	Double-riveted butt straps, with double straps for longitudinal seams.
S D	,,	Steam dome.
S N	,,	Steam neck.
M H	for	Man-hole and mud-hole openings.
L S	,,	Longitudinal stays.
S T	,,	Stay tubes.
G S	,,	Gusset stays.
C S	,,	Crown stays.
S S	,,	Screwed stays.

centre furnaces have one combustion chamber common to both. The two side furnaces have each a separate combustion chamber. The back and side plates are ½ inch thick, and are stayed with screwed stays 1⅛ inch diameter at bottom of thread, and pitched 8¾ inches apart; made of mild steel, and fitted with nuts at both ends. The tops of these chambers are curved to the arc of a circle of 26 inches radius.

The tubes are of iron, lap-welded, 249 in number (in each boiler), and 3¼ inches external diameter, and No. 9 B.W.G. in thickness, swelled at front end to 3⅜ inches diameter. The stay tubes are 75 in number (in each boiler), 3¼ inches external diameter, and 5/16 inch thick. These tubes are screwed into back tube plate, and fitted with nuts on combustion chamber side, and are secured into the front tube plate with nuts on each side.

The longitudinal stays in the steam space are 2⅛ inches diameter at bottom of thread, made of mild steel, and pitched 16 inches apart. Washers 7½ inches diameter, ½ inch thick, are fitted to each of the stays at both ends of boiler (outside). The end plates of the boiler were tapped, and stays screwed in, to a good fit, and afterwards caulked. The whole of the staying is sufficient for a working pressure of 90 lbs. per square inch.

Steam domes are fitted on each boiler 3 feet 6 inches diameter, and 7 feet long, with plates ½ inch thick. Their longitudinal seams are lap-jointed and double riveted; the circumferential seams being lap-jointed and single riveted. Their end plates are ¾ inch thick, dished to a circle 24 inches radius, and fitted with one steel stay in the centre, 2¾ inches diameter at bottom of thread. The domes are connected to the boilers by strong neck-pieces 16 inches diameter inside, and 12 inches long, and double riveted to shells of dome and boiler.

Man holes were cut in the shells of each boiler where shown, and they are fitted with wrought-iron doors, studs, bridges, &c., and compensating rings of flat plate, and double riveted to shell.

The complete boilers and steam domes were tested with water pressure to 180 lbs. per square inch, before leaving the works, without showing any leakage or signs of weakness.

The boilers rest on very strong wrought-iron seats riveted to the ship's floors, with double angle irons on the floors. The seats were well stayed in a fore and aft direction. The upper part of boilers were securely fastened to the ship's beams, in such a way as to allow of the boiler expanding without opposition from the stays.

After the boilers were fixed in the vessel and tested to 90 lbs. steam pressure, their upper parts and the steam domes were covered with an approved non-conducting composition, which

extends round as far as the centre of the wing furnaces, and then sheathed with sheet-lead and bound with strong iron hoops.

Each boiler has two spring-loaded safety valves, $4\frac{13}{16}$ inches diameter, with easing gear led to engine-room platform, one steam stop valve 7 inches diameter, one valve for steam to winches and cranes $2\frac{1}{2}$ inches diameter, one valve for steam to whistle, one surface blow-off valve, one bottom blow-off valve, one main feed check valve, one donkey feed check valve, one salinometer cock, two sets of asbestos packed gauge cocks; also an efficient means of circulating the water in boilers while steam is being got up. The whole of the above valve chests are of cast brass, with the exception of the safety-valve and stop-valve chests.

The furnace fronts, doors, and centre bar bearer are made of wrought iron, and the dead plates and bars of cast iron. Furnace fronts below dead plate are fitted with damper doors, with a rack to keep them open to the desired amount. A wrought-iron door is fitted to lower part of bridge bearer in each furnace, so that ashes or coal thrown over the bridges may be removed.

The uptake is formed of $\frac{1}{4}$ inch and $\frac{3}{16}$ inch wrought-iron plates, with an air space of 2 inches between them. The smoke-box doors have shield plates both outside and inside, and very strong hinges with brass pins riveted in. The funnel is formed of $\frac{1}{4}$ inch and $\frac{3}{16}$ inch plates, 43 feet high from fire bars, and 6 feet 6 inches diameter, with all necessary hoops and shackles for stays &c.

LECTURE XXVI.—QUESTIONS.

1. **Sketch a longitudinal section of a Cornish boiler; show clearly the method of connecting the ends to the shell and flue plates, and mark the water level. Where is the feed water admitted, and for what reason?** (S. and A. Exam., 1887.)

2. **Sketch a cross and a longitudinal section of a Cornish boiler, with a single-furnace tube and fire grate inside the tube. Describe your sketches by an index to the parts, and explain how the products of combustion pass from the furnace to the chimney.**

3. Sketch and describe in section an ordinary cylindrical two-flued Lancashire land boiler with flat ends and internal flues. How are these flues fitted with cross water tubes. Enumerate the principal fittings and their uses.

4. Sketch the front view of a Lancashire boiler, showing all the necessary fittings. State the uses of the principal parts in giving an index of them.

5. Describe Galloway's water tubes, usually fitted to cylindrical land boilers, and show how they are fitted into their position. What advantages are claimed by their adoption?

6. Describe the construction of a marine boiler with four furnaces of modern type for high-pressure steam. Sketch a cross and a longitudinal section, showing the water spaces, with a complete index of the various parts. How are the flat surfaces stayed?

7. Sketch front end view and a longitudinal section of a modern marine high-pressure multitubular boiler, and calculate the heating surface of 320 tubes, each 7′ long and 2″·75 external diameter. *Ans.* 1612·7 sq. feet.

8. If the inside diameter of a Lancashire boiler shell is 5′, and the outside diameter of each of the two internal flues is 25″, what space is there inside the boiler for steam and water if the length is 21′4″? *Ans.* 273·35 cubic feet.

9. The diameter of a cylindrical boiler being 13′ and the water level being one-fourth of the diameter from the top; if the boiler is 10′ long, what is the volume of the steam space? Also, what is the pressure per square inch on the bottom of the boiler when the steam pressure is 100 lbs. by gauge? *Ans.* 295·5 cb. ft.; 104·25 lbs.

10. Why are the longitudinal joints in cylindrical boilers usually double rivetted, while the transverse joints are only single-rivetted? Sketch in longitudinal section a marine high pressure boiler. (S. and A. Exam., 1889.)

See Lecture XXIX. of the Author's Advanced Text Book on "Steam and Steam Engines," for answer to first part of this question.

11. Draw a vertical section through the fire-box and tubes of a low-pressure marine boiler. Describe the method adopted for strengthening the weak portions. Mark in your drawing the combustion chamber, and state the object which it fulfils. (S. and A. Exam. 1890.)

12. Give (1) a longitudinal, (2) a transverse section through a Lancashire double-flued boiler, showing the probable water-line. Where is the feed water admitted, and for what reason? What is done to strengthen the shell of the boiler at the parts where it is most liable to give way under pressure. How are the flues secured against collapse? (S. and A. Exam 1891.)

13. Which joints of a Lancashire boiler are single-riveted and which are double-riveted? Explain why all the joints are not made of the same strength, and give some reason for such construction. Show by a sketch a double-riveted butt joint with cover plates. (S. and A. Exam. 1892.)

14. What is a Galloway tube, and what is its object? Sketch the transverse and longitudinal sectional elevations of a boiler in which such tubes are used. How are the ends of the boiler stayed? (S. and A. Exam. 1893.)

15. Draw a vertical longitudinal section of a single-ended return tube marine boiler of circular section. Show the method of staying the tube plate and combustion chamber. Show also the fire bridge, and state what end it serves. (S. & A. Exam. 1892.)

16. Sketch and describe the construction and action of a non-return feed-water valve for either a land or a marine boiler. Where and at what level is such a valve placed on the boiler? (S. & A. Exam. 1896.)

17. Make a longitudinal and also a transverse section of a Lancashire boiler with its brickwork settings. Indicate the course of the gases through the internal and external flues of the boiler to the chimney. Show also the construction of the fire-bridge and method of supporting the fire-bars. (S. & A. Exam. 1896.) (See also the Author's advanced "Text-Book on Steam and the Steam Engine," and Munro's "Steam Boilers," published by Chas. Griffin & Co.)

LECTURE XXVII.

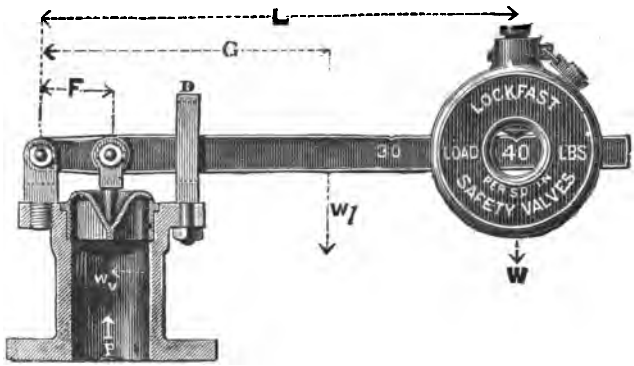
CONTENTS.—Boiler Mountings and Fittings—Safety Valves—Lever Safety Valves, with Examples—Dead-weight Safety Valve—Marine Boiler Safety Valve—Glass-tube Water Gauge.

Boiler Mountings and Fittings.—The necessary boiler mountings and fittings for an ordinary land boiler were enumerated in the index to parts given under the outside view representing a Lancashire boiler. Of these, we have already described the Bourdon steam gauge in Lecture XI. and the stop valve in Lecture XXII. Of the rest of the apparatus, that which claims our chief attention at present is the safety valve.

Safety Valves.—A safety valve is simply an ordinary circular steam-tight valve, fitted into a cast-iron chest, situated on the top of the boiler, and kept down with a pressure equivalent to that of the maximum working pressure of the steam on the under side of the valve. Its object is, therefore, to prevent the steam pressure in the boiler exceeding the working pressure. The pressure on the outside of the valve may be produced by a simple lever and weight as in the first figure, or by dead weight as in the figure (p. 268), or by a spring as in the figures (p. 269).

Lever Safety Valves.—The lever safety valve is, no doubt, the most common method of producing the required pressure on the valve in small land boilers. When properly made and fitted, it serves the purpose admirably. If, however, the weight on the lever is free to be moved, there is a liability of its being accidentally or intentionally shifted, which would bring a greater or less pressure on the valve. To prevent this, lockfast safety valves, marked with the precise load per square inch to which the valve is kept down, are now frequently demanded, and the following illustration shows very clearly how it is accomplished by means of a pointed bolt, lock, and key. The pointed bolt fits a niche in the lever at 40, and is held fast by the cross pin passing through the top of the weight, through the end of which pin the padlock ring is passed.

The rule for determining the dimensions of the valve, lever, and weight forms a very interesting example of the principle of moments. Adopting the same lettering and index to parts as in



ALLEY AND MACLELLAN'S LOCKFAST SAFETY VALVE.

Munro's book on *Steam Boilers,* from which the two next figures are taken—

Let L = the length of lever in *inches* from the fulcrum to the point at which the weight, W, is suspended.

F = the length of lever in *inches* from the fulcrum to the centre of valve.

G = the length of the lever in *inches* from the fulcrum to the centre of gravity of the lever.

A = the area of the valve in square inches $= \pi r^2 = \frac{\pi}{4} d^2$.

W = weight of the cast-iron ball or block on the end of lever in lbs.

W_l = weight of the lever in lbs.

W_v = weight of valve in lbs.

P = pressure of steam in the boiler in lbs. per square inch at which it is intended the valve should lift and "blow off."

The lengths, L, F, and G, should be ascertained with great accuracy by a rule, and the weights W, W_l, and W_v separately by an ordinary balance. To find the position of the centre of gravity or the distance, G, the lever should be balanced on a knife edge. The diameter of the valve, *d*, can best be found by a callipers.

Then, $$P = \frac{W \times L + (W_l \times G) + (W_v \times F)}{A \times F}.$$

The way in which this formula is combined will be easily understood if we take it in detail.

(1) The total upward pressure of steam acting on the valve $= P \times A$.

(2) This upward pressure has first to overcome the weight of the valve; therefore the nett or effective upward pressure $= P \times A - W_v$.

(3) The moment of this effective upward pressure about the fulcrum $= (P \times A - W_v) \times F$.

This forms one side of an equation, and must be balanced by the sum of the moments acting in the opposite direction.

(4) The moment of the weight W about the fulcrum $= W \times L$.

(5) " " " W_l " " $= W_l \times G$.

The sum of these moments $= \underline{W \times L + W_l \times G}$.

∴ *The upward moment = the sum of downward moments.*

$$\therefore (P \times A - W) \times F = W \times L + W_l \times G$$
$$P \times A \times F = W \times L + W_l \times G + W_v \times F.$$

By dividing both sides of the equation by $A \times F$, we get the last equation on p. 265.

In most elementary examinations the weights of the lever and of the valve are neglected. Then the equation is simply:

$$P \times A \times F = W \times L.$$

Since, in this case, the pressure at which steam will blow off is directly proportional to the distance L, if we know the pressure corresponding to a certain distance, we can by simple proportion find the pressure corresponding to any other position of the weight.

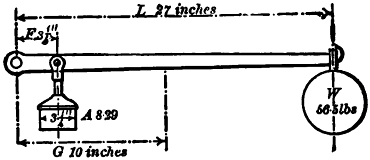
EXAMPLE I.—A safety valve 10 square inches in area, is held down by a lever and weight, the length of the lever from the fulcrum to the point where the weight is hung being 24 inches. The valve spindle is 3 inches from the fulcrum. You are to disregard the weights of the lever and valve, and find the pressure of steam per square which will lift the valve when the weight at the end of the lever is 40 lbs.

Here $A = 10$ square inches, $F = 3$ inches, $W = 40$ lbs., $L = 24$ inches. Substituting these in the formula above:

$$P \times 10 \times 3 = 40 \times 24$$
$$\therefore P = \frac{40 \times 24}{10 \times 3} = \underline{32 \text{ lbs.}} \text{ per square inch.}$$

If any other dimension be required, such as the position on the lever at which the weight must be placed (length L) in order that steam may blow off at a certain pressure; or, if it be required to find the diameter of the valve *d*, when the other dimensions are given, then, as shown in Lecture III., &c., we have only to substitute the known dimensions in the equation, and from these find the unknown one.

EXAMPLE II.—Taking the sizes given in the accompanying figure, let the weight of the lever = 8·5 lbs. and the valve = 2 lbs.



Find the pressure per square inch at which steam will blow off.
By formula—

$$P \times A \times F = W \times L + W_l \times G + W_v \times F.$$

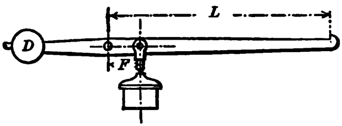
Substituting the numerical values—

$$P \times 8{\cdot}29 \times 3''{\cdot}25 = 56{\cdot}5 \times 27'' + 8{\cdot}5 \times 10'' + 2 \times 3{\cdot}25.''$$

$$P \times 26{\cdot}94 = 1617.$$

$$\therefore P = \underline{60 \text{ lbs.}} \text{ per square inch.}$$

EXAMPLE III. (from Science and Art Elementary Steam Examination, 1888).—The lever of a safety valve is balanced and is 24 inches in length; the distance between the fulcrum and the end of the valve spindle is 3 inches, the diameter of the valve being $2\frac{1}{2}$ inches. Find the weight to be put on the end of the lever in order that the steam may escape at a pressure of 50 lbs. per square inch, the weight of the valve being neglected. (Take $\pi = \frac{22}{7}$.)



The above figure, from Munro on *Steam Boilers*, represents the kind of balanced safety-valve lever mentioned in the question. It is evident that the weight of the lever and the moment arising therefrom do not enter into the solution of the question; further, we are told to neglect the weight of the valve.

The area of the valve, $A = \pi r^2 = \frac{22}{7} \times 1''{\cdot}25 \times 1''{\cdot}25 = 4{\cdot}9$ sq. in.

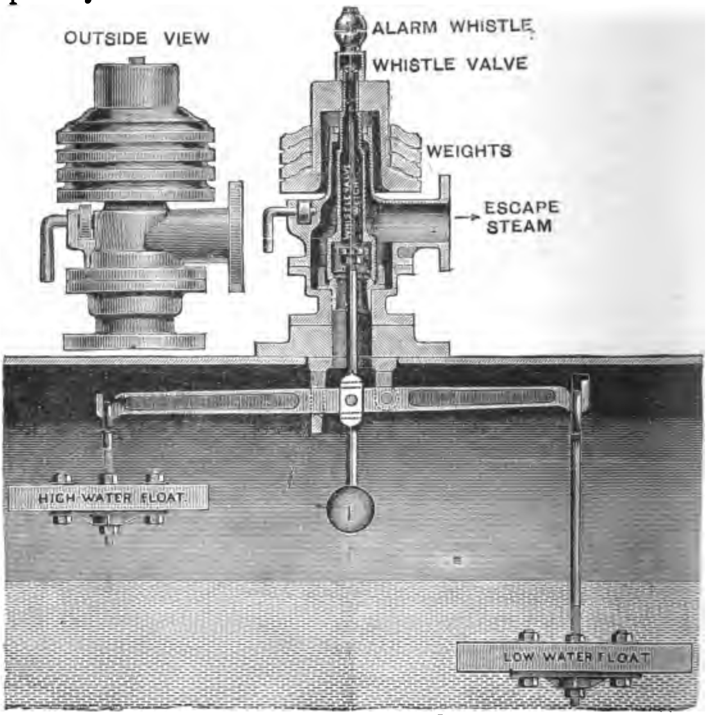
Consequently—

$$P \times A \times F = W \times L.$$

$$50 \text{ lbs.} \times 4{\cdot}9 \text{ sq. in.} \times 3'' = W \times 24.$$

$$\therefore W = \frac{50 \times 4{\cdot}9 \times 3}{24} = \underline{30{\cdot}8 \text{ lbs.}}$$

Dead-weight Safety Valve.—Dead-weight safety valves, if properly constructed, cannot be tampered with or jammed with the same ease as lever safety valves, and they are therefore becoming very popular for stationary land boilers. We here illustrate a very complete and successful form of dead-weight safety valve by a well-known firm who make safety and stop valves a speciality.



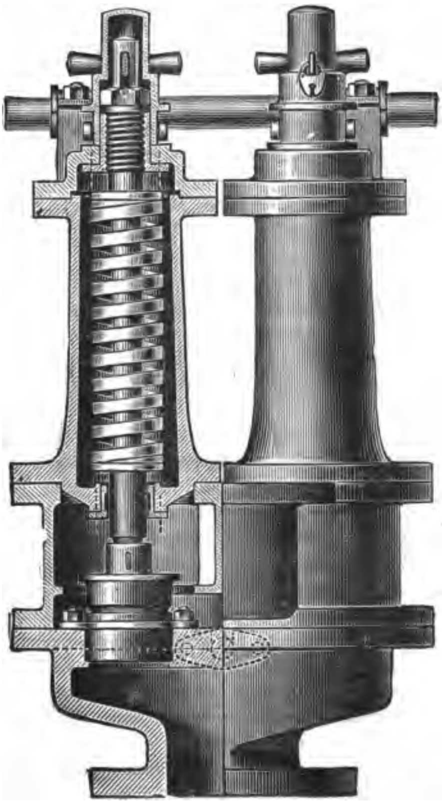
TURNBULL'S DEAD-WEIGHT SAFETY VALVE.

It will be seen from the figure that, in addition to acting as a safety valve, the apparatus in its complete form is made to do duty as a high-pressure, low-water, and high-water whistle alarm. For, should the pressure rise above the normal, the whistle valve is lifted by the direct pressure of the steam overcoming the long central weight attached to the whistle valve, and, should the water in the boiler be allowed to fall too low or rise too high, the corresponding float causes the whistle valve to lift and draw the attention of the attendant.

Using the same letters as in the case of the lever safety valve, the following formula expresses the relation between the area of the valve, pressure of steam, and dead weight—viz.:

$$A \times P = W.$$

Marine Boiler Safety Valves.—Neither lever safety valves nor dead-weight safety valves are suitable for marine boilers. The latter were used until within a few years ago, but the many disadvantages due to their great weight and the rolling of the vessel have caused them to be given up in favour of direct loaded spring valves. The arrangement of these valves will be easily understood from the following figure:—



TURNBULL'S DOUBLE, SPRING-LOADED SAFETY VALVE.

It will be observed that there are two valves, with springs quite independent of each other, entirely protected and locked, so that no one except those with due authority may screw down the springs and overload the valves. An easing lever shaft is fitted across the top part of the protecting chambers. This shaft may be connected by suitable chain and rod gear to the engine or boiler room, so that the engineer can ease the valves and "blow off" at any time.

We shall deal with locomotive boiler safety valves in the next Lecture, and in the meantime draw the student's attention to another important fitting for land and marine boilers—viz., the water gauge glass.

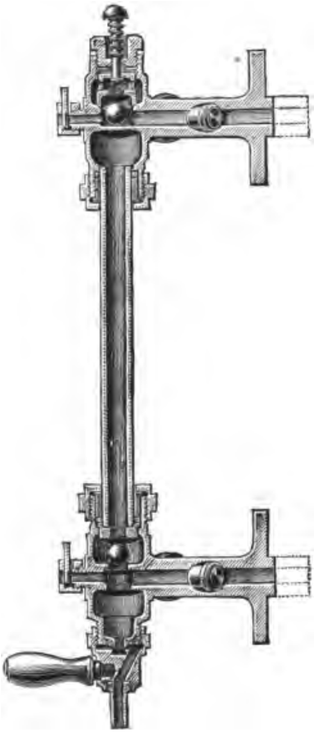
Glass-tube Water Gauges. — One of the most common causes of boiler explosions is "shortness of water." If the water in a boiler gets below the top of the furnace crowns or below the top of the upper tier of tubes, then the heat of the fire very soon softens the iron plates, or the hot gases soften the tubes, thus lessening their resistance to pressure, and as a consequence the internal pressure causes them to bulge inwards, and give way if the defect is not noticed and rectified in time. Many clever and (so-called) automatic arrangements have been invented and patented for preventing the water getting too low in boilers, but none of these devices has yet entirely superseded the use of the glass-tube water gauge. The simplicity of its construction and action, combined with the fact that the fireman must frequently inspect and test it in order that he may know the exact height of the water in his boiler, naturally tends to keep him constantly alive to his duties, and to its still being preferred by engineers to other forms.

The construction and action of this form of boiler water gauge will be readily understood from the following figures.

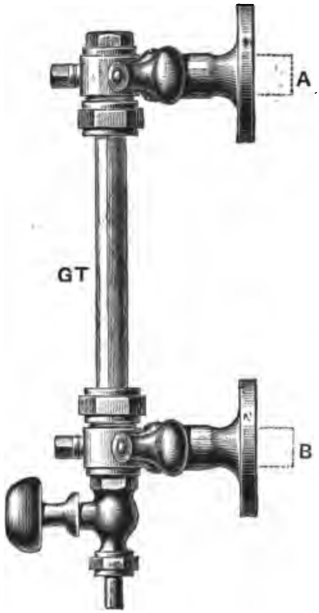
There should always be one, and in the case of large and important boilers, two glass-tube water gauges fitted in the most easily seen and got at positions in front of the boiler (see figs., pp. 254 and 256), so that if one is under repair, or not acting properly, the other may be relied upon. Three stop valves or cocks are fitted to each gauge—the upper one close to the screw plug, A, fitted into the boiler opposite to the steam space, the middle one close to the screw plug, B, fitted into the boiler opposite the highest part exposed to the fire or to the flames or to the hot gases from the furnace, and the lower one directly below the glass tube, G T. The upper and middle cocks are for the purpose of bringing the glass tube into shunt circuit with the steam and the water in the boiler, so that the water may pass through the middle cock and the steam through the upper cock, and therefore

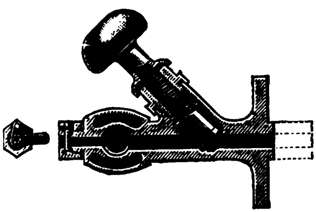
meet in the glass tube, and stand at the same level as in the boiler. The lowermost visible part of the glass tube should be at least 3 inches above the highest point inside the boiler acted on by

Section.

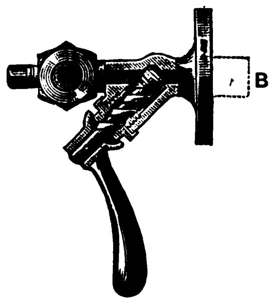


Outside View.





Sectional Plan.



Sectional Plan through B.

GLASS-TUBE WATER GAUGE, BY SCHÄFFER & BUDENBERG.

the flames or hot gases, and the water should *never* be permitted below this point when the boiler is at work. By shutting the middle cock and opening the lower one, at the same time keeping the upper one open, steam is blown through the glass tube. By shutting the upper cock and opening the middle and lower ones, water is blown through the lower cock, &c., and by shutting the upper and middle cocks the steam and water in the boiler are cut off from the glass tube, and it may be removed for cleaning, or for replacing it by another tube. These cocks should be tried two or three times every day, and the glass tube kept thoroughly clean.

In addition to the glass-tube water gauge, three ordinary cocks are frequently fitted to the boiler in order to ascertain the height of the water in it, should the glass tube break or fail to act. The upper cock is fixed on a level with the upper screw plug, A, in the last figure, the lower one on a level with the screw plug, B, and the middle one half-way between them. Steam should issue from the boiler upon opening the upper cock, water upon opening the lower one, and steam or water, as the case may be, when opening the middle one.

LECTURE XXVII.—QUESTIONS.

1. Sketch an ordinary lever safety valve as applied to a land boiler. The diameter of a valve is $3\frac{3}{4}$ inches; the leverage is 11 to 1. Find the pull on the end of the lever when the steam pressure is 30 lbs. above the atmosphere. *Ans.* 30·1 lbs.

2. Required the weight to be placed on the end of a safety-valve lever 18 inches long, diameter of valve, $2\frac{3}{4}$ inches, distance from fulcrum to valve, 3 inches, the upward pressure on the valve required for lifting the valve and lever being 20 lbs., and the pressure of steam in the boiler being 100 lbs. per square inch above that of the atmosphere? *Ans.* 95·7 lbs.

3. Steam is required to blow off at 60 lbs. by gauge. The weight to be placed on the end of an ordinary safety-valve lever is 56 lbs., the weight of the lever is $8\frac{1}{2}$ lbs., and the valve weighs 2 lbs. At what position on the lever from the fulcrum must the weight be placed, if the diameter of the valve is $3\frac{1}{2}$ inches, and if the distance from the centre of the valve to the fulcrum is 3·25 inches, while the centre of gravity of the lever is 10 inches from the same point? *Ans.* 27 inches.

4. What weight must be placed on a balanced lever at 27″ from the fulcrum in order to just counteract steam pressure of 60 lbs. per square inch, if the radius of the valve is 1·75″ and the distance from the fulcrum to the centre of the valve is 3·25″? *Ans.* 59·27 lbs.

5. What diameter should a safety valve have in order that steam of 100 lbs. pressure may blow off; the other sizes being the same as in Question 3?

6. Sketch and describe a safety valve loaded with direct weights, and point out what advantages it has over an ordinary lever valve.

7. If 630 lbs. dead weight is put on a safety valve 4″ diameter, at what pressure will steam blow off? *Ans.* 50 lbs. per square inch.

8. A safety valve blows off at 25 lbs. per square inch. What is its diameter if 820 lbs. be the dead weight on the valve? *Ans.* 6″·5.

9. What weight and bulk of lead will be required for the dead weight on a safety valve 3″ diameter to blow off at 50 lbs. per square inch if the valve and spindle weigh 16 lbs. *Ans.* 337 lbs.;

10. Sketch and describe a marine boiler safety valve with a spiral spring for loading the valve, and explain why this form is better than a dead weight or lever and weight for the purpose.

11. Describe the water gauge for ascertaining the height of the water in any steam boiler. Show its position with reference to the fire box of the boiler, and sketch a longitudinal section through the gauge. (S. and A. Exam., 1887.)

12. Sketch and describe the following safety valves:—
   (1) An ordinary lever valve.
   (2) The Ramsbottom spring loaded valve.
   (3) An ordinary dead weight valve. (S. & A. Exam., 1889.)

13. Sketch a vertical section of a dead-weight safety-valve. (No marks will be given for the ordinary lever safety valve.) If the valve is $2\frac{1}{4}$ inches in diameter, with a dead weight of 300 lbs., at what steam pressure per square inch will the valve lift. (Take $\pi = 3\frac{1}{7}$.) S. and A. Exam. 1891.) *Ans.* 75·42 lbs.

14. Describe and sketch the construction of a glass water gauge and its mounting, as adapted for use in a steam boiler. Where is such a gauge placed, and at what height? How is its working tested? (S. and A. Exam. 1892.)

15. Describe and sketch a dead-weight safety valve. Such a valve is 2 inches in diameter; the weight of the valve and spindle is 20 lbs. What dead-weight would require to be added so that steam should blow off when the pressure reached 80 lbs. per square inch? (S. and A. Exam. 1894.) *Ans.* 241·33 lbs.

16. A safety valve of 3 inches diameter is held down by a lever and weight. The lever is 30 inches long, and the valve centre is 4 inches from the fulcrum, the suspended weight on the lever being 56 lbs. At what pressure of steam would the valve be lifted, the weight of the lever being neglected in the computation? Sketch the valve, its seating, and the general arrangement. (S. & A. Exam. 1895.)

17. Sketch the construction of a lever safety valve with balance weight, and state under what circumstances such a construction could not be used. If the lever be 16 inches in length and the centre of the valve seat is 4 inches from the fulcrum, while the diameter of the valve is 4 inches; find the weight to be placed at the end of the lever so that steam may blow-off at a pressure of 45 lbs. per square inch, the weight of the valve and of the lever being neglected. (S. & A. Exam. 1896.)

LECTURE XXVIII.

CONTENTS.—Longitudinal and Cross Sections through a Modern Locomotive Boiler—Description of Boiler—Locomotive Regulator Valve and Safety Valves.

INDEX OF PARTS TO THE LOCOMOTIVE.

Combustion and Heating Arrangements.

F D, for Fire Door.
F D H, „ Fire-door Handle.
F B, „ Fire Bars, on which the coals are placed, with spaces between them to allow air to pass up through the coals and cause combustion; and to allow ashes to fall into the ash pan.
B, „ Bearers, for supporting **F B** at both ends.
D P, „ Deflector Plate, for deflecting the gases as they rise from the coals, and causing them to mix properly; thus ensuring a more complete consumption of the smoke.
B A, „ Brick Arch, also for deflecting the gases and preventing them from rushing along the tubes as they rise from the coals.
F Bx, „ Fire Box, in which the products of combustion should assume the form of a colourless gas. Its sides are usually made of copper, as then they transmit the heat to the water more quickly than they would if made of iron, and resist better the action of the fire.
F T P, „ Fire-box Tube Plate.
T, „ Tubes, along which the heated gases pass on their way to the chimney, heating the water which surrounds them. They are fixed at the one end to **F Bx,** and at the other to **S B.**
T P, „ Smoke-box Tube Plate.
S B, „ Smoke Box, from which the smoke passes on through—
Cy, „ Chimney.
S B D, „ Smoke-box Door, which admits of access to the boiler tubes and steam pipes.

Boiler.

O S, for Outer Shell, in three lengths, Front, Middle, and Fire-box Shell. The front is secured to the smoke-box tube plate, **T P,** by an outside cylindrical angle iron. The middle length is also cylindrical, and is attached to the front length by a lap joint. The fire-box shell is cylindrical on the top, but flat on the sides, to allow of its going between the main frames, **M F**; it is secured to the middle length by a lap joint.

S D, for Steam Dome (on side and end views). It is placed on the top of the middle length of the outer shell of the boiler, and is used for collecting dry steam and for holding the steam regulator.

C S, „ Copper Stays (on end view), for securing the outer shell of the fire box to the inside fire box, and thus strengthening both of them.

F B R S, „ Fire-box Roof Stays, for preventing the flat roof of the copper box from collapsing.

S S, „ Sling Stays, which are attached by pins to **F B R S,** and also to angle irons riveted to the roof of outer shell, thus causing the weight of the fire box to be carried by the outer shell, and bracing the two together.

L S, „ Longitudinal Stays (on side and end views), for staying smoke-box tube plate and back plate of fire-box shell together.

Pm S, „ Palm Stay, to support fire-box tube plate, **F T P.**

F E B, „ Fire-box Expansion Bracket (on end view). This forms a support for boiler, and at the same time allows for any expansion caused by heat.

F P C, „ Fusible Plug for Fire-box Crown (separate sketch of boiler).

Steam Regulating Gear.

(Shown on Boiler and Detail Sketches, p. 281.)

S R H, for Steam Regulator Handle.

R S B, „ Regulator Stuffing Box.

S R R, „ Steam Regulator Rod; the end of this rod inside the boiler is supported by a footstep, as shown.

C L, „ Connecting Link between **S R R** and **S R V** for actuating—

S R V, „ Steam Regulator Valve, for governing the admission of steam from the steam dome to the cylinders.

R V, „ Relieving Valve, for relieving the full pressure of steam from **S R V,** and thus rendering it easily opened, as well as to allow the driver to start the locomotive gently. **R V** works directly on the back of **S R V.** It opens first and shuts last.

S R P, „ Steam Regulator Pipe, made of cast iron.

C I S P, „ Copper Internal Steam Pipe.

S P C, „ Steam Pipe to Cylinder Valve Chests (on side view of boiler).

S E P, „ Steam Exhaust Pipe, or "Blast Pipe."

Safety Valve Gear.

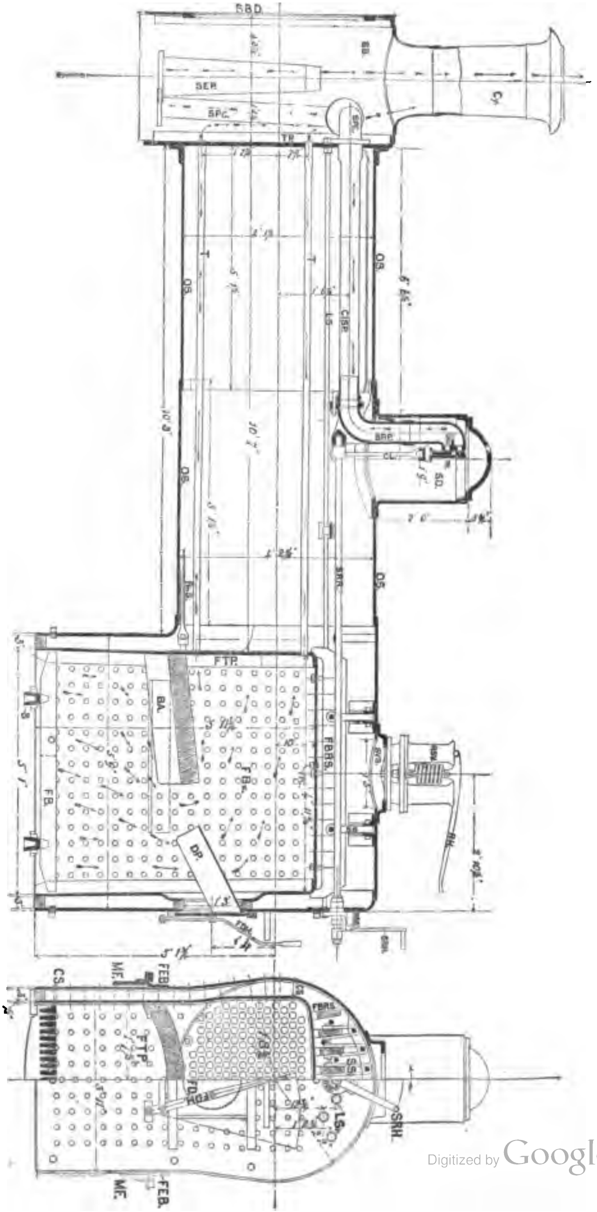
(Shown on Boiler and Detail Sketch, p. 282.)

R S V, for Ramsbottom Safety Valves.

S V S, „ Safety Valve Seat, which is bolted to a man-hole, formed on the top of the outer shell of fire box.

B V, „ Brass Valves.

R H, „ Relieving Handle, which extends into **C A B.** The driver, by pulling or pushing the end of this lever, can let steam escape from one or other of the safety valves at pleasure, or ascertain that they are not sticking in their seats.



SECTION THROUGH LOCOMOTIVE BOILER,
Constructed by Messrs. Dubs & Co., Glasgow Locomotive Works, for the London, Chatham, and Dover Railway Company.

DESCRIPTION OF LOCOMOTIVE BOILER, ETC.

Boiler.—The barrel, dome, fire-box casing, tube plates, all angle irons, rivets, and stays were made of Lowmoor iron. The barrel is telescopic, and made in two plates, the circumferential seams being single riveted, and the longitudinal seams butt jointed with inside and outside strips, double riveted. The tube plate is attached to barrel by a ring of angle iron, bored, faced, turned on edges and shrunk on, and zigzag riveted to both. The dome is in one plate, welded at the seam, and flanged at the bottom to fit barrel, to which it is double riveted. A strengthening liner plate is placed inside the barrel, round the opening for the dome. The top has an angle iron ring riveted to it, and is fitted with a strong wrought-iron cover, the cover and angle iron being accurately faced so as to make a perfectly steam-tight joint.

The fire-box shell was made as shown, the sides and top being in one plate. The front or throat plate was flanged forward and single riveted to the barrel, and the back plate to the sides and top as shown. Angle irons for carrying the sling stays were riveted to the top in the position shown.

The man hole is of wrought iron, flanged top and bottom, and single riveted to the casing, the top flange being accurately faced to receive the safety valves. The boiler is stayed by six longitudinal stays, screwed into the back plate of casing, and passing through the smoke-box tube plate, with nut and washer on either side. The back plate is strengthened where the stays pass through by a liner plate, riveted to it on the inside. The longitudinal stays are supported in the middle of their length, in the manner shown. The fire hole is circular. The ring of the section shown is of Yorkshire iron, and riveted to the casing and fire-box plates. The foundation ring is also of Yorkshire iron, with the corners of the form shown, carefully riveted so as to be thoroughly tight.

Dimensions of Barrel, &c.

	Ft.	In.
Length of barrel	10	3
Diameter „ outside at fire-box end	4	3
Thickness „ plates	0	$0\frac{7}{16}$
„ of tube plate	0	$0\frac{7}{8}$
„ of dome „	0	$0\frac{9}{16}$
Length of fire-box shell	5	9
Breadth „ „ at bottom outside	3	11
Depth „ „ from centre line of boiler	5	2
Thickness „ „ plates	0	$0\frac{1}{2}$
Section of foundation ring, 3 inches × $2\frac{3}{4}$ inches.		
„ fire-hole „ 2 „ × $2\frac{5}{8}$ „		
Diameter of rivets in boiler	0	$0\frac{11}{16}$
„ „ foundation ring	0	$0\frac{7}{8}$
Height of centre line of boiler from rail	7	2

Fire Box.—The fire-box plates and stays are of copper of the very best quality. The plates were annealed, both before and after flanging, and strips were cut off and tested by being doubled cold, without showing any sign of fracture. They were also analysed, and found to contain less than ·5 per cent. of impurities. The sides and crown are in one plate. The crown is curved as shown, and stayed with eight Yorkshire iron roof

bars of the section shown, each secured by thirteen studs 1 inch diameter, screwed through the crown plate into the bar, with nut on the underside of plate. Six of the roof bars are connected to the angle irons on the casing plate by twelve sling stays of Yorkshire iron. Great care was taken to bed the ends of the roof bars accurately on the fire-box plates, and to see that the sling stays were of the correct length and bearing on the pins top and bottom.

The tube plate is stayed to the barrel by six 1-inch copper stays, screwed through the plate into palm stays riveted to the barrel. The copper stays were screwed tightly into the fire box and casing plates, and neatly riveted over at the ends, the thread being turned off the portion between the plates. A brass plug with fusible centre was inserted in the crown of the fire box. A brick arch was built in the fire box and supported on studs in the manner shown. The fire-box back plate was dished at fire hole to meet the ring and the fire hole fitted with an air deflector scoop, and sliding doors, in the manner shown on the drawings.

Fire grate consists of nineteen wrought-iron fire bars, and two cast-iron fire bars of the section shown, supported on two cast-iron comb bar bearers by four wrought-iron brackets, studded to foundation ring. The fire box is riveted with the best Yorkshire iron rivets.

Dimensions of Fire Box.

	Ft.	In.
Length at top outside	5	0½
" bottom	5	2
Breadth "	3	4
Depth inside	6	0
Water space at bottom, all round	0	3
Thickness of plates	0	0½
" tube plate	0	0$\frac{15}{16}$
	and	
	0	0½
Diameter of fire hole	1	4½
" rivets	0	0$\frac{7}{8}$
" copper stays	0	0$\frac{7}{8}$
	and	
	0	1

All the plates were planed or turned on the edges before being put together. The holes were drilled and rimed out perfectly fair with each other in all plates and angle irons. Before being lagged the boiler was tested to a pressure of 200 lbs. per square inch with water, and afterwards to 160 lbs. per square inch with steam, and found to be perfectly tight under these pressures.

Tubes.—The tubes are of copper, solid drawn, No. 9 B.W.G. at the fire-box end, tapering to 12 B.W.G. at the smoke-box end. They were secured by a roller tube expander and fixed with ferrules at the fire-box end. The ferrules were of ferrule steel, and were put into the tubes a tight driving fit. The tubes project through the smoke-box tube plate about $\frac{1}{16}$ inch.

Dimensions of Tubes.

	Ft.	In.
Number (199).		
Length between tube plates	10	7
Diameter outside	0	1¾
„ „ at smoke-box end for a length of 6 in.	0	1⅛
Thickness at fire-box end (No. 9 B.W.G.).		
„ smoke-box end (No. 12 B.W.G.).		
Distance apart of centres . . . . . about	0	2⅛

Smoke Box and Spark Arrester.—The plates for smoke box and door are of BB Staffordshire iron, having a perfectly smooth surface. The rivets were countersunk outside and filed smooth. Wrought-iron liners were placed against the tube plate and the sides and front of smoke box. The door was dished, as shown on drawings, and fitted with baffle plates and suitable dart, handles, and hinges; the latter were finished bright.

A wrought-iron grate for arresting sparks is supported in the smoke box in a horizontal position, just below top of blast pipe.

Dimensions of Smoke Box, &c.

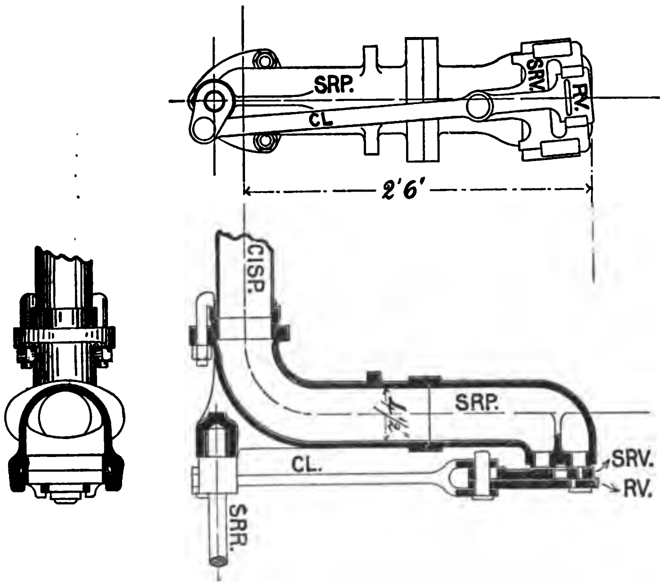
	Ft.	In.
Length of smoke box (inside)	2	8⅛
Width on centre line of boiler (inside) . . .	4	11
Thickness of plates	0	0⅜
Section of angle iron (2½ in. by 2½ in. by ½ in.).		
„ ring round door holo (3 in. by ¾ in.).		
Diameter of rivets	0	0⅝
Pitch of rivets . . . . about	0	3

Chimney.—The chimney is of BB Staffordshire iron, jointed with a butt strip, and the rivets countersunk, and filed smooth on the outside. The bottom was carefully fitted to smoke box. The top is of cast iron, of the shape shown in the drawing.

Dimensions of Chimney.

	Ft.	In.
Height of top of chimney from rail	13	3⅞
Diameter inside at top	1	6
„ „ bottom	1	5
Thickness of plates	0	0¼

Regulator and Steam Pipes.—The regulator is of cast iron, and the head fitted with double valves. The steam pipes are of copper sheets, hard soldered together on the inside. The flanges and cone are of brass. The steam pipe in the boiler is fixed to the tube plate by a turned ferrule of the best steel, and to the regulator by means of three claw bolts.



REGULATOR FOR DUBS & CO.'S LOCOMOTIVE.

DIMENSIONS OF REGULATOR, &C.

	Ft.	In.
Diameter of steam pipes (inside)	0	$4\frac{1}{2}$
Thickness ,, ,, (No. 7 B.W.G.).		

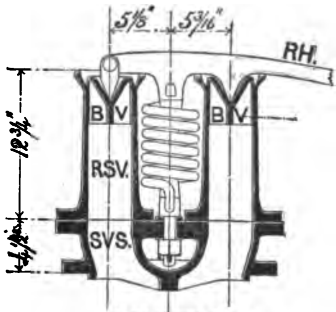
Exhaust or Blast Pipe.—The blast pipe to be of cast iron, the top to be turned and bored to the form shown.

DIMENSIONS OF EXHAUST PIPE.

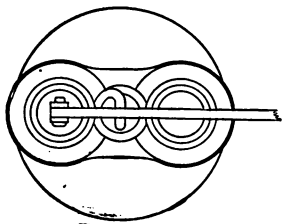
	Ft.	In.
Diameter of blast orifice	0	$4\frac{3}{4}$
Height of blast pipe above top row of tubes . .	0	2

Safety Valves.—These are of the kind known as "Ramsbottom's duplex" safety valves. They are fixed on the fire-box casing. The

columns are of brass turned bright, fixed on a cast-iron man-hole cover. The springs were set so as to blow off at 140 lbs. per square inch. All the joints were accurately faced, and found to be perfectly steam-tight.



SECTION.



PLAN.

RAMSBOTTOM'S SAFETY VALVE FOR DUBS & CO.'S LOCOMOTIVE.

DIMENSIONS OF SAFETY VALVES.

	Ft.	In.
Diameter of valves . .	0	3½
Distance apart of columns .	0	10 5/16
Height of brass columns .	1	0¾
Diameter of spring steel .	0	0 13/16
„ man-hole cover	1	6
Thickness of seat . .	0	1⅛

Locomotive Boiler Safety Valves.—The following figures serve to illustrate an arrangement of safety valve for locomotives and portable land boilers which is more convenient than any known arrangement of dead weights or dead weight and lever. Instead of a weight, the end of the lever is pulled down by a "Salter's" spring balance, and, in order that the ordinary graduations on these balances may serve to indicate the pressure in lbs. per square inch in the boiler, the levers are usually proportioned, as shown in figures, where the length from the centre of the valve to the centre of the fulcrum, or F, is made equal to the diameter of the valve, d, and the total length of the lever, L, is made equal to the diameter of the valve multiplied by the area, A. The weight of the valve and lever being small, and the pressure per square inch great, the former is usually neglected.

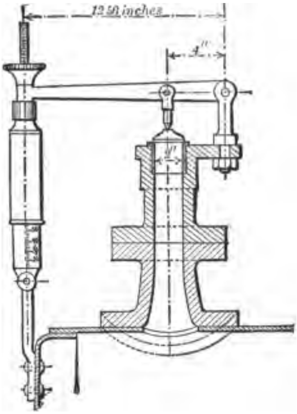
Thus, by our former formula for the lever safety valve—

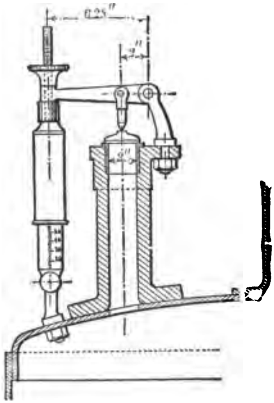
$$P \times A \times F = W \times L.$$

Substituting the above ratios—

$$P \times A \times d = W \times A \times d.$$

$$\therefore P = W.$$





By thus arranging these proportions, each lb. of pressure of steam per square inch on the valve corresponds to a lb. pull on the "Salter's" spring balance.

Generally, locomotives are fitted with two safety valves placed close together, and actuated by one spring and cross bar, as shown. In order that each valve may be subjected to the same downward pull from the spiral spring, Mr. Turnbull has devised a simple arrangement of screw pin, with square ends, as shown in the next figure and in plan at A, whereby the driver may move the spring nearer or further from one of the valves, and thus make certain that both the valves shall blow off simultaneously.

A

LOCOMOTIVE SAFETY VALVE

Lecture XXVIII.—Questions.

1. In designing locomotive boilers it is necessary to provide for a sufficiently large amount of heating surface and a sufficiently strong draught. Sketch a section through a locomotive boiler, describing the manner in which these two requisites are provided for. (S. & A. Exam., 1888.)

2. Sketch a section through the entire length of a locomotive boiler, showing the fire-box and smoke box. Mark the positions of the safety valve and regulator valve.

3. Sketch a section through the fire box of a locomotive boiler, showing particularly the method of supporting the flat surfaces, and explain your drawing by an explanatory index of parts.

4. Describe, with sketch and an index of parts, the steam regulator, valve rod and handle, for a locomotive engine. State the conditions essential for the successful working of a regulator valve in a locomotive engine.

5. Sketch and describe a safety valve suited for a locomotive boiler.

6. Sketch and explain a lever safety valve with Salter's balance. How can the readings on the balance which are graduated to lbs. pull on the spring be made to indicate the pressure per square inch of steam in the boiler?

7. Sketch and describe Ramsbottom's safety valve. Sketch also an ordinary safety valve with Salter's spring balance. Mention the respective advantages of each.

8. If the pull of the spring of a locomotive safety-valve lever is 80 lbs., the length from fulcrum to valve being $3\frac{1}{2}''$, from valve to spring $21''$, and diameter of valve $3''$; what pressure per square inch will the steam have when blowing off? *Ans.* 79·2 lbs.

9. Describe, with such sketches as you think necessary, the construction and arrangement of parts in either a marine, or stationary, or locomotive engine, whichever you are most familiar with. (S. and A. Exam. 1890.)

10. Sketch a longitudinal section through a modern locomotive boiler showing the smoke box and the method of staying the fire box, and point out briefly the chief improvements now introduced. (S. and A. Exam. 1893.)

11. Describe a form of safety valve such as is frequently used on locomotive boilers where two valves connected by a lever are held down by a spring applied between the valves, showing by sketches the construction of the appliance. (S. and A. Exam. 1893.)

12. Describe, with such sketches as you think necessary, the general construction of a locomotive engine. (S. and A. Exam. 1894.)

APPENDIX.

Questions *from the Elementary Stage of the Science and Art Department's Examinations in* Steam, *from* 1890 *to* 1896, *which are not included at the end of the Lectures. To each question a reference is made where the subject is treated.*

1. Sketch the Newcomen engine in sectional elevation. During what portion of each stroke, and in what manner, was heat unnecessarily wasted by Newcomen's arrangement? How did Watt propose to lessen the waste of heat, and in what way did he carry out his idea? (S. and A. Exam. 1891.) *

2. State concisely the chief improvements which Watt made in the steam engine, so as to give some idea of the mode in which they were carried out. Sketch in section Watt's single-acting engine, and explain its working. (S. and A. Exam. 1892.) *

3. Describe, with the necessary sketches, the changes introduced by Watt in order to convert an engine in which the steam was employed for lifting a pump-rod, into the modern form of engine as employed for driving the machinery in factories. (S. and A. Exam. 1895.) *

4. What were the chief improvements made by Watt in the atmospheric pumping engine? Draw an approximate indicator diagram of such an engine, before the improvements to which you refer were introduced. (S. and A. Exam. 1894.) *

5. Describe Hornblower's compound or double cylinder engine, and explain by sketches the manner in which the steam passes through the cylinders into the condenser. You can take either the single- or double-acting engine. (S. and A. Exam. 1890.) *

6. Assuming that the steam in a steam cylinder expands according to Boyle's law, show how to find the terminal pressure for any given boiler pressure and cut-off, and how to find the mean pressure during the stroke; then assuming that the boiler pressure is 100 lbs. absolute per square inch

* See Author's Text Book on Steam and Steam Engines.

and that the cut-off takes place at ¼ of the stroke, determine what would be the terminal pressure, and also the mean pressure in the cylinder for the whole stroke. (S. & A. Exam. 1895.) (See Lect. XIII.)

7. Make a sketch and describe the construction of one form of piston cross-head with which you are acquainted. Under what conditions may a slipper slide for the piston cross-head be employed in a horizontal engine? (S. and A. Exam. 1896.) (See Lect. XVI.)

8. What would be the indicated horse-power of a locomotive when moving at a steady rate of 35 miles per hour on a level rail, the weight of the train being 130 tons and the resistance to traction 10 lbs. per ton? (S. and A. Exam. 1896.) (See Lect. XVII.)

9. The cylinder of a steam-engine is 20 inches in diameter, the crank-arm is one foot long, and the connecting rod is 4 feet long. Find the turning effort on the crank shaft at the instant when the crank-arm makes a right angle with the connecting rod, the pressure of the steam being 60 lbs per square inch. (S. and A. Exam. 1891.) *Ans.* 19,4 lbs. nearly.*

10. A steam engine has a steam cylinder of 20 inches in diameter, the crank measures 18 inches from the centre of crank-shaft to centre of crank-pin, the engine runs at 85 revolutions per minute, and the mean effective pressure of steam on the piston is 28 lbs per square inch. Find the indicated horse-power of the engine. (S. and A. Exam. 1896.) (See Lect. XVII.)

11. Describe and sketch the general arrangement of the cylinder, the piston and its rod, with the connecting rod, and the method of coupling it to either the crank or beam, and the method of keeping the end of the piston-rod in a straight line, in *one* of the following types of engine:—(1) An inverted vertical high-pressure engine; (2) A beam engine; (3) A horizontal stationary engine. State some fundamental differences of construction between (1) and (2.) (S. and A. Exam. 1895.) (See Lect. XX.) *

12. Describe and sketch the construction of a double-beat or equilibrium valve. When and for what purpose are such valves used? In such a valve the two seats measure respectively 8 inches and 7½ inches in diameter, and the weight of the valve is 70 lbs. What pressure per square inch would cause the valve to lift, the pressure between the valve discs being disregarded? (S. and A. Exam. 1896.) (See Lect. XXII.)

13. Make a sketch and describe the construction of an eccentric sheave and strap. Show the position of the crank-shaft through the eccentric, and indicate on your sketch the throw of the eccentric. Name the materials of which the several parts of the eccentric are made. (S. and A. Exam. 1896.) (See Lect. XXIII.)

14. Sketch and describe fully the construction of an air-pump bucket with its valve or valves; show also the packing of the bucket, and explain the use and mode of action of the air-pump. (S. and A. Exam. 1895.) (See Lect. XXIV.)

* See the Author's Text Book on Steam and Steam Engines

15. What do you understand by jet and surface condensation respectively? Give a sketch of each arrangement. There are in a surface condenser 1000 brass tubes, each of 6 feet in length, and 1 inch outside diameter. What amount of cooling surface would such a condenser provide? (S. & A. Exam. 1895.) (See Lect. XXIV.)

16. Sketch and describe the construction of the air-pump of a condensing engine. What is the use of the air-pump? If the temperature of the injection-water supplied to a jet condenser be 62° F. and the water is pumped out of the hot well at a temperature of 106° F., and the steam to be condensed enters the condenser at a temperature of 212° F., what weight of injection water would be required per pound of steam condensed? (S. and A. Exam. 1896.) (See Lect. XXIV.)

17. Describe, with sketches, an oscillating marine engine. How is the steam conveyed to the steam chest, and afterwards to the condenser? In what class of steamers are oscillating engines commonly employed, and why? (S. and A. Exam. 1894.) (See the Author's Text Book on Steam and Steam Engines, Lect. XIX.) *

18. Describe, with a sketch, an oscillating marine engine. How is the steam conveyed to and from the slide valve casing? In what class of steamers are oscillating engines generally employed, and why? (S. and A. Exam. 1895.) *

19. Write a short description of the "Rocket" locomotive, as invented by Stephenson, and point out its chief features, giving any reasons you can for its success over rival inventions. (S. and A. Exam. 1893.) *

20. Sketch in section the piston of a small engine working with high-pressure steam, such as a locomotive engine, together with the piston rod and cylinder cover, showing the metallic packing for the piston and the stuffing box and gland for making the piston-rod steam-tight. Explain the reasons for the construction which you adopt. (S. and A. Exam. 1890.) *

21. Describe, with the necessary sketches, the construction of a locomotive piston, piston-rod, and crosshead, and state clearly how the several parts are secured together. (S. and A. Exam. 1895.) *

22. Explain the principle of Watt's invention of a parallel motion for connecting the ends of the piston and air-pump rods with the working beam of a steam engine. Make such sketches as you may think necessary for explaining your answer. (S. and A. Exam. 1890.) * (See also Lect. XVIII.) †

23. What is the use of a fly-wheel as applied to a steam-engine? How does its action upon the working of an engine differ from that of the governor? Sketch in elevation the governor of an engine. (S. and A. Exam. 1890.) ‡

24. Explain the difference between the functions of a fly-wheel and

* See Author's Text Book on Steam and Steam Engines.
† See Vol. I., Author's Text Book on Applied Mechanics.
‡ See Vol. II., Author's Text Book on Applied Mechanics.

governor, giving a clear idea of the influence of each upon the running of an engine. Sketch any form of governor, showing what are the attachments by which it controls the engine. (S. and A. Exam. 1894.) ‡

25. Explain the action of an ordinary governor of a steam engine. How is the throttle valve connected with the governor? Sketch the arrangement. Explain also the action of the fly-wheel, and why it is so necessary in stationary engines. (S. and A. Exam. 1892.) ‡

26. What are the chief causes of the collection of scale within a boiler? Of what does boiler incrustation usually consist, and in what parts of the boiler is the collection most objectionable and why? Give a section through the furnace of either a land or marine boiler, showing its general construction, and mark where the scale may be expected to collect. (S. and A. Exam. 1895.) (See Seaton's *Manual of Marine Engineering*, and Munro's *Steam Boilers*, by the publishers of this book.)

‡ Vol. II, Author's Text Book on Applied Mechanics.

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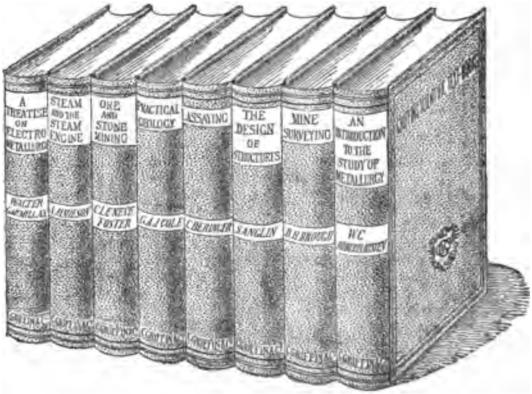

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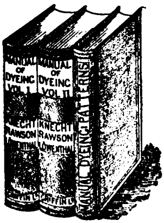

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